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Diagnostico comparativo del funcionamiento y la productividad del regadío en el Valle del Río Senegal en Mauritania. Opciones de mejora.

Comparative diagnosis of irrigation performance and productivity along the Senegal Valley in Mauritania. Opportunities for improvement.

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TITULO: *DIAGNOSTICO COMPARATIVO DEL FUNCIONAMIENTO Y LA PRODUCTIVIDAD DEL REGADÍO EN EL VALLE DEL RIO SENEGAL EN MAURITANIA. OPCIONES DE MEJORA*

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TÍTULO DE LA TESIS: Diagnóstico comparativo del funcionamiento y la productividad del regadío en el valle del río Senegal en Mauritania. Opciones de mejora.
Comparative diagnosis of irrigation performance and productivity along the Senegal valley in Mauritania. Opportunities for improvement

DOCTORANDA: Cecilia Borgia

INFORME RAZONADO DEL/DE LOS DIRECTOR/ES DE LA TESIS

(se hará mención a la evolución y desarrollo de la tesis, así como a trabajos y publicaciones derivados de la misma).

Tras su formación en la Universidad de Wageningen, donde obtuvo el título de Máster Internacional en Gestión de Agua y Territorio, la doctoranda cerró un período intenso de formación práctica en gestión del riego y de comunidades de regantes en varios países en desarrollo, Mauritania incluida. Adquirió en este período conocimientos y experiencia sobre técnicas, métodos y principios participativos aplicados a la investigación del riego. A continuación, la doctoranda aplicó estos conocimientos a la evaluación comparativa y el diagnóstico del regadío en el valle del río Senegal, utilizando para ello métodos de investigación y enfoques interpretativos novedosos que han culminado en un estudio vasto que cumple las exigencias de rigor científico e innovación propias de una tesis doctoral.
La investigación desarrollada por la doctoranda ha sido ya objeto de dos artículos en las revistas científicas más importantes del ramo. Un tercer artículo está listo para ser sometido a evaluación también en una revista científica de alto impacto. Por último, se espera someter a discusión un cuarto estudio con vistas a que también sea objeto de un artículo científico, éste con un enfoque de política de regadío en Mauritania.

Por todo ello, autorizo la presentación de la tesis doctoral.

Córdoba, 7 de Junio de 2012

Firma del director

Fdo.:Luciano Mateos Íñiguez

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I am very greatful to the technical staff in Mauritania that participated in the field surveys and that enabled collecting all the relevant information that forms the basis of this thesis. Thank you very much Mamadou Dia, Amadou Bousso, Seyid Ould M. Vadel, Yahya Sow, and Lo Souleymania, for sharing insights and helping me understanding better the context I was researching in.

My special thanks go also to Daniel Lozano for the valuable contribution to the analysis of satellite images and GIS maps development.

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List of abbreviations

A	Adequacy
AB	Agribusiness
CPB	Casier Pilote de Boghé
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DPCSE	Direction de Politiques, de la Coopération, du Suivi, et de l'Evaluation
EC	Energy Cost
E	Equity
F	Flexibility
FP	Fuel Productivity
HCA	Hierarchical Cluster Analysis
IAE	Indicator of Application Efficiency
IDE	Indicator of Distribution Efficiency
IDPIAM	Integrated Development Programme for Irrigation Agriculture in Mauritania
II1	Irrigation Intensity referred to the irrigated area
II2	Irrigation Intensity referred to the irrigable area
LP	Land Productivity
LPS	Large Public Schemes
PIS	Private Irrigation Schemes
PPGII	Périmètre Pilote du Gorgol II
R	Reliability
RAP	Rapid Appraisal Process
RIS	Relative Irrigation Supply
S	Score
SCMS	Small Community-Managed Schemes
SII	Small Individual Irrigation
SONADER	Société Nationale pour le Developpement Rural
SSA	Sub-Saharan Africa
TE	Technical Efficiency
WDC1	Water Distribution Capacity referred to the irrigated area

WDC2	Water Distribution Capacity referred to the irrigable area
WF	Weighting Factor
WG	Women Garden
WP	Water Productivity

Summary

In the last fifty years, concerted efforts have been spent on improving irrigation technology and management, both in academic and professional circles. Despite all this, irrigation has failed to keep up with projected results. Understanding of causes and processes behind this poor performance is needed, especially in regions like the Sahel, where irrigation could play a fundamental role for food security and livelihoods. This research deepens into the causes of low productivity and abandonment of rice-based irrigated agriculture in the Senegal River valley in Mauritania. Performance assessment and benchmarking are means by which it is possible to analyse and compare water management practices within and across irrigation schemes while identifying measures to improve irrigation delivery service and resources use. Four were the specific objectives of this study. First, to evaluate the performance and variability in productivity and input use of a number of small- and large-scale irrigation schemes. Second, to study patterns of spatial variability of land productivity and water use in large irrigation schemes. Third, to establish benchmarks for productivity and performance that shall serve as reference for the improvement of irrigation schemes. Fourth, to draft concrete and fundamental propositions on what irrigation models are most appropriate for the conditions in Mauritania and how to steer future policy actions consequently.

Rapid appraisal process (RAP) and benchmarking techniques allowed systematic compilation of technical, organisational, institutional, and financial information. Data collected during repetitious field visits, semi-structured interviews, and direct measurements constituted the basis for the calculation of external and internal irrigation performance indicators used in the comparative analysis of the irrigation schemes. The indicators used were: irrigation intensity, water delivery capacity, relative irrigation supply, land productivity, water productivity, energy productivity, equity, reliability, flexibility, adequacy, and efficiency. Rice production was measured in a representative sample of plots in each studied irrigation scheme. Water use was quantified based on flow rate measurements and records of pumping time. Benchmarking was based on hierarchical cluster (HCA) and data envelopment (DEA) analyses that allowed, respectively, grouping and ranking of irrigation schemes according to a set of indicators previously obtained from the performance assessment.

Benchmarking of small and large schemes showed that land productivity and

technical efficiency were highly variable in irrigation schemes along the Senegal valley in Mauritania; however, both DEA and HCA showed that there were some productive and efficient schemes. DEA also identified the particular efficient schemes that should be taken as reference for improvement of each inefficient scheme.

Performance assessment indicated that the state of the infrastructure and irrigation management are key factors in determining the variability of productivity and efficiency. Drainage turned out to have a greater influence than irrigation in determining intra-scheme spatial variability of yield and irrigation intensity in large schemes. Comparison of small- and large-scale irrigation schemes showed that, on a pure technical basis, large schemes did not perform worse than small schemes. However, small schemes showed greater variability, which may indicate a larger margin for improvement and also existence of successful schemes.

The analysis of strengths and weaknesses of alternative irrigation models in Mauritania and their future perspectives for food security indicated that both large- and small-scale rice schemes are caught in a process known as “rehabilitation followed by deterioration trap” which must be reversed through the development of management capacity and physical upgrading of the irrigation infrastructure. Complete transfer of large schemes can only be pursued after extensive training, physical upgrading, and improved yields. The contribution of horticulture-based irrigation models to food security, poverty alleviation, and gender-equitable wealth creation lies in the development of a supportive environment of institutions and services for the autonomous replication of these systems. More research on the potential of private irrigation and agribusinesses, and related threats, is needed. Finally, sound policy planning and implementation requires updated national statistics that today are not available.

Resumen

En los últimos cincuenta años, tanto en el ámbito científico como en el profesional se han producido muchos esfuerzos para mejorar la tecnología y la gestión del riego. Sin embargo, al menos en los países en desarrollo, los resultados están todavía muy por debajo de las expectativas, a pesar de que el regadío constituye un suporte importante de la seguridad alimentaria y el sustentamiento de las poblaciones locales. En este contexto se coloca esta investigación, que pretende profundizar en las causas de la baja productividad y del abandono del regadío orientado a la producción de arroz en el valle del Río Senegal en Mauritania.

La evaluación del funcionamiento de perímetros de riego y la identificación de los que pueden servir de referencia son medios para el análisis y la mejora de la calidad del servicio de riego y la eficiencia del uso de los recursos. Cuatro son los objetivos concretos de esta tesis. Primero, evaluar el funcionamiento de un conjunto de perímetros de riego grandes y pequeños, así como analizar las causas de la variabilidad de su productividad y la eficiencia. Segundo, estudiar los patrones de variabilidad espacial de la productividad y el uso del agua de los grandes perímetros de riego. Tercero, establecer fronteras ("benchmarks") de productividad y eficiencia que sirvan de referencia para la mejora de los perímetros de riego. Cuarto, proponer recomendaciones fundamentales y concretas sobre qué modelos de riego se adaptan a las condiciones de la región y, sobre ello, plantear políticas y actuaciones futuras.

Las metodologías "rapid appraisal process" (RAP) y "benchmarking" han permitido obtener y analizar sistemáticamente información sobre aspectos socio-económicos, institucionales, de infraestructura y de gestión del riego. La información recompilada en visitas periódicas, entrevistas semi-estructuradas y medidas directas ha servido para calcular los siguientes indicadores del funcionamiento interno y externo de los perímetros: intensidad del riego, capacidad de suministro de agua, suministro relativo de riego, productividad de la tierra, productividad del agua, productividad de la energía, equidad, flexibilidad, adecuación y eficiencia. El rendimiento del arroz se midió en una muestra de parcelas en cada perímetro. El volumen de agua utilizada se determinó a partir de medidas del caudal de bombeo y del registro del tiempo de bombeo en cada perímetro. El "benchmarking" se basó en análisis de conglomerados (AC) y análisis envolvente de datos ("data envelopment analysis", DEA), que permitieron agrupar y

ordenar los perímetros según un conjunto de indicadores previamente obtenidos con la metodología RAP.

Los resultados de la evaluación mostraron gran variabilidad entre los perímetros de riego con respeto a la productividad y la eficiencia del uso de los recursos. Sin embargo, tanto AC como DEA indicaron que hay perímetros que destacan por su productividad y eficiencia. DEA sirvió además para identificar los perímetros más eficientes que pueden servir de referencia para cada uno de los perímetros menos eficientes.

El diagnóstico comparativo mostró que la gran variabilidad encontrada es debida en mucha parte a la infraestructura y a la gestión del riego y del drenaje. En los grandes perímetros, el drenaje es un factor clave en la determinación de la variabilidad espacial de la productividad y la intensidad de riego. Contra lo comúnmente expresado, las grandes zonas regables no funcionaron peor que los pequeños perímetros.

Grandes y pequeños perímetros colectivos de arroz están atrapados en un círculo vicioso de degradación-rehabilitación que hay que romper con mejoras tecnológicas, institucionales y de las infraestructuras. La transferencia de los grandes perímetros a las comunidades de regantes solo será posible una vez que se haya invertido en formación y capacitación y después de mejoras infraestructurales. Otros modelos de riego como los basados en la producción hortícola son importantes para alcanzar la seguridad alimentaria. Sin embargo, para que sean replicables autónomamente, tienen que ser acompañados del desarrollo de infraestructuras, mercados y servicios apropiados. Los perímetros privados y las grandes inversiones con capital extranjero requieren un estudio más profundo de su potencial y riesgos asociados. Por último, las políticas de riego y su actuación práctica requieren estadísticas robustas y actualizadas que por el momento faltan en Mauritania.

Chapter 1

General Introduction

1. General Introduction

1.1. Introduction

In the last fifty years, concerted efforts have been spent on improving irrigation technology and management, both in academic and professional circles. Many irrigation schemes have been modernised and transferred to users. Despite all this, irrigation has failed to keep up with projected results, especially in developing countries, where irrigation could play a fundamental role for food security and local livelihoods.

Much has been written for instance about the inefficiency and inefficacy of large-scale irrigation in Sub-Saharan Africa. However, at a time when national governments and the international community are again willing to invest in irrigation in that region, many questions remain open: What are the causes of the large yield gap? What irrigation models respond best to the conditions of Sub-Saharan Africa? What type of management could lend better results, private or public, and under which circumstances? What level of irrigation technology matches best local actors' management and financial capacity? What cropping system could best sustain food security? This research deepens into the causes of low productivity and abandonment of irrigated agriculture in the Senegal River valley in Mauritania, a representative case for the river-fed irrigated systems of the Sahel, and gives response to these questions.

1.2. Irrigation performance assessment

Scientific and technological bases to improve irrigation management have known a great leap especially since the 1970s. At that time, the focus was on soil-water-plant relations and on improving water application schedules (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979), while advances in water measurement and control from hydraulic engineering sought to deliver precise discharges of water to the plot (Merriam and Keller, 1978; Bos et al., 1984). The 1980s witnessed a shift in approach to irrigation improvement: engineering solutions were discredited *vis a vis* managerial solutions. While managerial and institutional aspects are still very popular today in irrigation circles, they have been integrated with concepts of participatory irrigation management

(PIM) and it is also recognised that they should be in equilibrium with technology and design components (Horst, 1998; Plusquellec, 2002).

Irrigation performance assessment was introduced in the 1990s as an essential means to improve irrigation service delivery and resources use efficiency (Bos et al., 2005). Pioneer works were those of Molden and Gates (1990), Small and Svendsen (1990), Murray-Rust and Snellen (1993), and Bos et al. (1994), who elaborated internal and external irrigation indicators for evaluating irrigation performance. First studies considered single irrigation schemes or separate system levels in order to identify measures for continuous improvement according to pre-established, implicit or explicit, objectives (Bos et al., 2005). Skogerboe and Merkley (1996) developed a process of evaluation-reaction of maintenance and operation for improving equity and dependability of irrigation water supply. Bautista et al. (2000) analysed the quality of the water delivery service in an irrigation district in Arizona as part of a broader programme (Management Improvement Programme) directed at improving the performance of irrigated agriculture. Lozano and Mateos (2008) employed irrigation indicators and a decision support system (SIMIS) to enhance irrigation scheduling and water distribution in an irrigation scheme of the Canal Bajo del Guadalquivir, Spain. In the Sahel, Vandersypen et al. (2006) analysed water delivery processes at tertiary system level in the Office du Niger in Mali.

Comparative performance assessment was introduced later as a more effective means to identify and propose measures for general irrigation improvement. For this purpose, new irrigation indicators were designed that were more appropriate for cross-scheme comparison (Molden et al., 1998; Malano and Burton, 2001; Bos et al., 2005) and benchmarking, a tool typically employed in the business sector for identifying performance references (Burt and Styles, 2004; Malano et al., 2004). The development of rapid rural appraisal techniques represented a key element in this type of analysis as it allows the systematic, comprehensive, and, most importantly, rapid diagnosis of various irrigation schemes. One of the first benchmarking studies in the irrigation sector was the one by the Australian National Committee on Irrigation and Drainage (Alexander and Potter, 2004) while equally significant were the works of Molden et al. (1998), Kloezen and Garcés-Restrepo (1998), and Burt and Styles (1999). In Spain, the studies by Rodríguez-Diaz et al. (2004a, 2004b; 2008) and, more recently, the one by Córcoles et al. (2011) represent pioneer applications of benchmarking to the study of irrigation districts and irrigation technology in the Mediterranean setting.

The possibility to compare heterogeneous irrigation schemes or irrigation technologies has been theme of much debate, particularly as to the interpretation of results. Worldwide, there are few studies of irrigation performance that combine the comparison of homogeneous schemes with in-depth analysis of internal irrigation processes in each scheme.

This was the **first main objective** of this thesis that combines the analysis of variability of production factors in collective rice irrigation schemes with productivity measures, in order to better understand the drivers and internal processes that lead to the yield gap. A first hypothesis was that by quantifying and understanding the drivers of yield and performance variability it is possible to establish benchmarks for productivity and the actually achievable yield frontier. A second hypothesis was that by examining the sources of variability it is possible to diagnose concrete causes of unsatisfactory performance of irrigation schemes and to draft policy recommendations for their improvement.

For the specific objectives of this thesis, it is appropriate to differentiate between cross-scheme and intra-scheme yield variability. In Mauritania, yield variability between plots (in the range 0 to > 9 t ha^{-1}) has been subject of copious studies by different authors (Haefele et al., 2000; Haefele et al., 2001; Haefele et al., 2002; Poussin et al., 2003). Other authors linked yield uniformity within an irrigation scheme to uniformity of water distribution (Clemmens, 2006; Clemmens and Molden, 2007). Poussin (1998), Poussin and Boivin (2002), and Poussin et al. (2006) went beyond the study at plot level and found that yield variability was connected to both heterogeneous individual and collective motivation and practices. These works can be viewed as precursors of comparative assessment studies and analyses of yield variability across schemes, such as the type of analysis presented in this thesis. Other antecedents are that of Barbier et al. (2011), who classified different irrigation typologies in the Sahel on the basis of their sustainability and technical, social, and economic efficacy, and the work of Comas et al. (2012), who ranked 12 irrigation schemes along the Senegal River valley in Mauritania according to their efficiency in using inputs and labour.

1.3. Setting the context

In Mauritania, low precipitation constrains agriculture to only 0.5 % of its area, almost entirely confined in the Senegal River valley. Irrigation was introduced there out of the need to guarantee food self-reliance to a population whose livelihoods had been severely endangered by repetitious droughts during the 1960s and 1970s. However, since its introduction, irrigated agriculture has failed to deliver the expected outcomes: less than 40 % of the initially equipped area is currently exploited. In consequence, Mauritania relies heavily on imports and food aid, which together make up 72 % of the supply in cereals and 48 % of rice consumptions (FAO, 2007).

Assessment of irrigated agricultural systems in Mauritania ascribes low profitability and performance of collective irrigation to farmers' practices and their incapacity to adequately manage irrigation schemes (Poussin and Boivin, 2002). However, as in other regions in West-African Sahel, irrigated agriculture in the Senegal River valley is characterised by great variability in production in both time and space (Haefele et al., 2001).

Being rice at the base of Mauritanians' diet, its production will continue to play an important role for food security, which legitimates the discussion on what should be changed in order to increase productivity and sustainability of irrigation schemes. Refurbished international attention in irrigation development in Sub-Saharan Africa (Inocencio et al., 2007; World Bank, 2008; Turral et al., 2010; Nakano et al., 2011; Fujiie et al., 2011) and the vivid debate on its success factors for technology adoption and poverty alleviation (Keller and Roberts, 2004; Dillon, 2008; Gebregziabher et al., 2009; Hanjra et al., 2009) are ground for reflection on weaknesses and opportunities of alternative irrigation models in Mauritania. Moreover the debate on whether small- or large-scale farming responds better to present and future challenges of food security has not been solved yet (Deininger and Byerlee, 2012). There is a rich body of past and recent literature dedicated to smallholder irrigation (IPTRID, 2001; Hazell et al., 2010; Poulton et al., 2010; Dillon 2011; Burney and Naylor, 2012). At the same time, staple food production has lost interest *vis a vis* horticulture in papers that deal with poverty alleviation and food security (Weinberger and Lumpkin, 2007). This dichotomised view rarely contemplates the coexistence of alternative irrigation models and its importance for food security. Already in the 1990s, planners were looking for an irrigation model that could best suit environmental and socio-economic conditions in the Senegal River Valley (Crousse et al., 1991; Diemer and Huibers, 1991). Today, more than twenty years later, planners are still in search for that model, or for adaptations and improvements of existing models.

Thus, a **second main objective** of this thesis is to critically discuss future perspectives of different irrigation models in Mauritania, with a special focus on rice schemes. It will try to answer as crucial questions as: What is the potential contribution of existing irrigation models to food security and livelihoods? What role do small and large rice schemes play? What technical and managerial changes must rice schemes undergo in order to reach sustainability and thus better contribute to food security? What new irrigation models should be sustained?

1.4. Specific objectives

The specific objectives of this thesis were:

1. To establish benchmarks for productivity and performance that shall serve as reference for the improvement of irrigation schemes in Mauritania.
2. To evaluate the performance of a number of irrigation schemes in Mauritania, both small-scale and large-scale, and to analyse causes of variability in productivity and input use efficiency.
3. To study patterns of spatial variability of land productivity and water use in large irrigation schemes in Mauritania.

4. To draft concrete and fundamental propositions on what irrigation models are most appropriate for the conditions in Mauritania and how to steer future policy actions consequently.

In order to address the specific objectives, the research unfolded as follows: The study concerned 22 small community-managed irrigation schemes and 3 large public schemes for rice. Rapid appraisal process (RAP) and benchmarking techniques allowed the systematic and structured compilation and analysis of information (Molden et al., 1998; Burt and Styles, 1999; Burt, 2002). Data collected during repetitious field visits, semi-structured interviews, and direct measurements constituted the basis for the calculation of external and internal irrigation indicators (Molden and Gates, 1990; Malano and Burton, 2001; Bos et al., 2005) used in the comparative analysis of the irrigation schemes. The information encompassed technical, organisational, institutional, and financial aspects.

Moreover, during the period of study, private irrigation schemes and women-led irrigation farming were surveyed in an attempt to further characterise irrigation models in Mauritania. A total of 17 private farmers and 19 women gardens, equally distributed among the regions of Trarza, Brakna, and Gorgol, were visited. Information gathered included irrigation infrastructure and equipment, irrigated surfaces, cropping pattern, ethnic group, land tenure, management, labour, and financing mode.

The thesis is structured in chapters. After this introduction, Chapter 2 opens with a presentation of the various farming and irrigation models in Senegal River valley. It further discusses the access to and importance of agricultural statistics for policy making. In Chapter 3, a benchmarking of small- and large-scale rice schemes is presented in which schemes are compared, ranked, and grouped based mainly on external indicator. Chapter 3 also discusses potential and actual productivity frontiers. Chapter 4 goes deeper into the causes and processes behind poor performance and productivity in small rice schemes by analysing internal irrigation processes, and organisational and socio-economic factors. In Chapter 5 the same is done for large rice schemes. The focus in Chapter 5, however, is on the analysis of spatial variability of land productivity and the understanding of its drivers. Having discussed rice schemes more in depth, Chapter 6 reintroduces again the different irrigation models presented in Chapter 2. Chapter 6 not only delves their respective contribution to food security and livelihoods but also proposes concrete and fundamental steps for their improvement. Finally, Chapter 7 drafts general conclusions and recommendations generated by the research.

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Chapter 2

Existing irrigation models in Mauritania

2. Existing irrigation models in Mauritania

2.1. Farming and irrigation models

Various agro-ecosystems coexist in the Senegal valley. sketches a cross-section (a) and a plan view (b) of the river floodplain and associated farming systems. Most apart from the river, extensive shrubland grazing (*brousse*) of goats and sheep cohabits with fenced rainfed agriculture during summer (*dieri*) (Connor et al., 2008). Traditional cropping also includes two flood recession systems in the river floodplains, which encompass about 13,500 ha (DPCSE, 2009). In the *falo* system, maize and cowpea are directly sown on the river banks, whereas *walo* is based on sorghum and cowpea grown on more extensive areas that get inundated yearly by floods. Flood recession crops are sown during October-November and harvested in February-March (Comas et al., 2012).

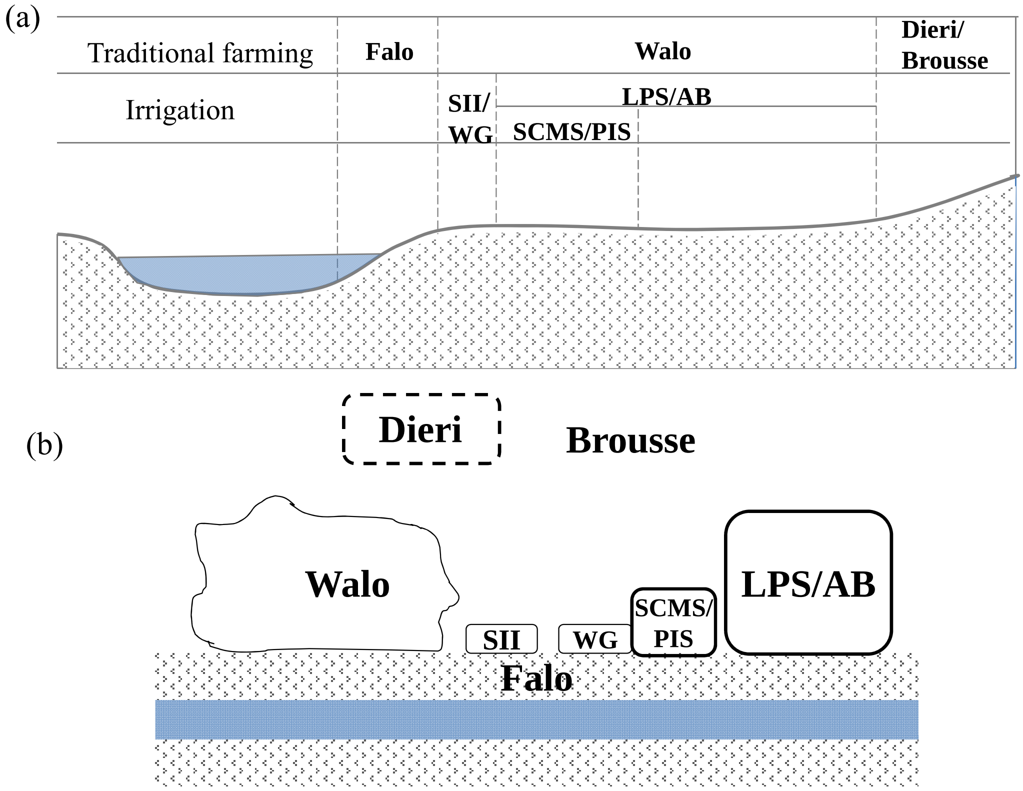

Figure 2.1. Cross-section (a) and a plan view (b) of the river floodplain and the associated agro-ecosystems.

Next to the area under traditional flood recession agriculture, there is a diversity of full-water control irrigation systems (Figure 2.1). Main criteria for their classification were cropping system (rice versus horticulture), management (collective versus private), and size. Table 2.1 presents the different irrigation models and their main features. Rice-based, collective schemes include large public (LPS) and small community-managed schemes (SCMS). Privately owned and managed irrigation schemes (PIS) are also mainly rice-based. Small individual irrigation (SII) and women garden (WG) are small-scale horticulture-based production systems that are managed by single households or collectively. Agribusinesses (AB) grow commodities (maize, soybeans, fruit trees) and are largely sustained by foreign capital. This classification largely coincides with that of the African Regional Association of Irrigation and Drainage (ARID, 2004) developed for five Sahelian countries: Burkina Faso, Mali, Mauritania, Niger, and Senegal.

LPS are entirely state- or donor- funded and owned by the state. SCMS and PIS may or may not have used public funds for their construction (ARID, 2004; Barbier et al., 2011). The state agency for rural development (Société Nationale pour le Developpement Rural, SONADER) has been the foremost actor in planning, implementing, and supervising collective rice irrigation schemes. LPS are more complex in their design, have several levels of infrastructure and show greater technicality than SCMS. Management is hierarchical and organised according to the level of intervention (plot, tertiary unit, main level). Farmers reunite in a multitude of cooperatives that jointly cultivate the scheme and take collective decisions within the board of a union of constitutive cooperatives. Overall, management is typically shared between SONADER and the union of cooperatives, although responsibilities are increasingly being transferred to farmers. Recently, also individual land users, not affiliated to any cooperative, started renting or buying out larger (3−10 ha) plots in LPS.

The functioning and performance of SCMS in Mauritania and more generally in the Senegal valley has been subject of study by several authors (Poussin, 1998; Poussin and Boivin, 2002; IPTRID, 2004). SCMS are generally rudimental in their layout and infrastructure. While at the origin there was greater participation of the community in the construction of these schemes (Diemer and Huibers, 1991), they have now become more complex, technical, and costly. Each scheme is managed by one cooperative of small farmers (plots of 0.1 to 0.8 ha) belonging to the same village. The cooperative organises irrigation and production activities (input, credit, land preparation, and harvest).

Table 2.1. Main features of the different existing irrigation models in Mauritania

Irrigation model	Size (ha)	Funding	Management	Water supply and distribution
LPS	500−2000	State/Donors	Collective: SONADER/ cooperatives/individuals	Gravity or pumping station; hierarchical network of lined or earthen irrigation canals; drainage system; manual or (semi-)automated water control
SCMS	20−140	State/Donors/NGO/Private	Collective: cooperative	Motor or electro-pump; simple earthen canal network; only recent schemes have drainage system
WG	< 30	State/Donors/NGO/Private	Collective: cooperative	Supply from village rice scheme or with own pump; simple canal network
SII	< 3	Private/NGO/Donor	Individual or collective	Small individual pump; small distribution canals or drip irrigation
PIS	20−200	Private local investors/ public funds	Individual or company	Pump/pumping station; open canal network, sprinkler or drip irrigation
AB	>200	Private national and/or foreign capital	Company	Pumping station; advanced irrigation technology

Irrigation model	Crop	Plot size (ha)	Labour
LPS	Rice (main), mixed crops	0.3−1 (coops. members); 1−20 (individuals)	Family/employees
SCMS	Rice (main), mixed crops	0.1−0.8	Family
WG	Vegetables (main)	−	Individual/family
SII	Cereals, vegetables, fruit trees	−	Individual/family
PIS	Rice (main), cereals, vegetables, fruit trees	−	Employees
AB	Maize, soybeans, wheat, fruit trees	−	Employees

What is generally referred to as private irrigation includes a rather diverse ensemble of actors and practices. Its main feature is the ownership of an individual water intake and distribution system. The dynamic and unexpected evolution of PIS in Mauritania was already reported in early studies (Crousse et al., 1991). Since the1980s, the lower valley began supporting the development of medium size private exploitations near the river estuary, while the middle valley developed with small size community-managed schemes (Barbier et al., 2011). Size of PIS ranges from 10 ha to more than 200 ha, although the majority of farms fall between 20 and 40 ha. Like SMCS and LPS, PIS are mainly devoted to rice, but it is quite common that horticulture and fruit trees are cultivated as a second crop on smaller surfaces during the dry season. As in collective schemes, PIS largely rely on credits for financing farming and irrigation (DPCSE, 2004). Private landholders usually recur to several employees and have their own machinery. PIS developed initially thanks to non-agricultural capital (local businessmen and politicians) and governmental support (ARID, 2004; Sylla 2006; Barbier et al., 2011). Later, they also benefitted from low interest loans made available by the World Bank within the Integrated Development Programme for Irrigation Agriculture in Mauritania (IDPIAM) started in 1999. Several other elements underpin their expansion: easy access to large land lots thanks to a Land Reform Act of 1983, soaring land values, low investments, and state policies endorsing food self-sufficiency (Barghouti and Le Moigne, 1990).

Agribusinesses are a recent experience in Mauritania and the result of a global wave of resurgent interest in land investments after the food crisis of 2007−08 (Deininger and Byerlee, 2012). Although still confined, the great availability in land and water resources and the regulatory vacuum are attractive factors to initiatives of this kind, which are also facilitated by the government and the connection with local powers. AB base their production on staple food other than rice (wheat, maize, soybeans) and large fruit plantations, although bio fuel also figures as a possible future target of private endeavours.

Small individual irrigation (SII) in Mauritania refers to smallholders (0.5−2 ha) who, generally with the aid of family labour, conduct a more diversified cropping system based principally on horticulture, but also on rice, other cereals, and fruit trees. There are no statistics about the total area under SII in Mauritania. Recently, SII has been recipient of training and extensive donations of irrigation equipment under the VISA project. The project provided packages of small pumps (2.5−5 hp) and small-scale water distribution networks. 350 ha, belonging to 270 farmers, were equipped following this irrigation model (Diallo, 2011).

As in other countries of the Sahel, in Mauritania women play a fundamental role in producing irrigated vegetables (Barbier et al., 2011). Once grown directly on the river banks, with the changed river hydrology following the construction of Manantali dam river upstream, vegetables are now largely grown on separate small irrigation perimeters or on extensions of rice schemes. Irrigation of these women gardens (WG) is made possible either by diverting water from rice schemes, through a shared common canal, or by means of pumps owned by the women cooperatives.

2.2. Irrigation information: availability, access, and reliability

There are two institutions in Mauritania that compile agricultural statistics: "Direction de Politiques, de la Coopération, du Suivi, et de l'Evaluation" (DPCSE) and SONADER. Whereas the former collects global data on agricultural production, the latter tracks more detailed information on the irrigation schemes it implemented and now supervises.

The potentially irrigable area on the Mauritanian side of the Senegal River valley is estimated in 136,500 ha, of which 45,000 ha were equipped with irrigation infrastructure (DPCSE, 2004; FAO, 2005). Irrigated area has decreased since the mid 1990s: in 1994, the irrigated area was estimated in 40,261 ha; by 2004, when FAO elaborated the statistics for AQUASTAT, the reported irrigated area had fallen to 22,840 ha (FAO, 2005). The data that the authors obtained from DPCSE indicated that this area fell further to 18,326 ha in 2008 (DPCSE, unpublished results).

Statistics in AQUASTAT attribute 21 %, 27 %, and 52 % of the total equipped area to respectively LPS, SCMS+WG, and PIS+SII (FAO, 2005), corresponding to 8461, 10,700, and 21,100 ha, respectively. However, statistics provided by DPCSE indicated that in 2008 the actual irrigated area was 3,393 ha, 3,340 ha, and 11,595 ha for, LPS, SCMS, and PIS, respectively.

Irrigation statistics were incomplete and sometimes contradictory, particularly, data on evolution of actual irrigated surfaces by the different irrigation models. As each year surfaces are abandoned due to degradation and new land is put under irrigation, often privately, shifts in percentages belonging to each category may easily go unaccounted for.

The estimation of production may be even more inaccurate than the estimation of irrigated area. For instance, yield estimated by SONADER in the wet season 2010−2011 in two large schemes, CPB and PPGII, were, respectively, 50 and 21 % higher than yields measured by the authors in the same schemes. An evaluation of the yield estimation method used by SONADER indicated that sampling was biased toward large yield. Statistical projections (i.e., FAOSTAT) on national agricultural production and imports are based on estimations available from national agencies (i.e., SONADER). Considering this, rice imports reported by FAO (2007) to be 48 % of national demands could be in reality higher.

Contrarily to agricultural statistics, soil and climate information needed for irrigation planning is quite complete and reliable. Since climatic information recorded by AGHRYMET at the weather stations in Rosso, Kaedi, and Selibaby was sparse, the authors grouped the data in a single data base with time series starting in the 1960s. Information on soil characteristics and agricultural potential was available in PNUD-FAO (1977) maps.

Chapters 3−5 address specifically collective rice schemes. As a matter of clarity, whenever it is referred to as “small” and “large” irrigation schemes, it is meant small community managed schemes (SCMS) and large public schemes (LPS), respectively. Thus, Chapter 3 presents a benchmarking analysis of SCMS and LPS, Chapter 4 comprises a performance assessment of SCMS, and Chapter 5 analyses performance and productivity in LPS.

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Chapter 3

Benchmarking for performance assessment of small and large irrigation schemes along the Senegal Valley in Mauritania

3. Benchmarking for performance assessment of small and large irrigation schemes along the Senegal Valley in Mauritania[1]

Abstract

Degradation of irrigation schemes, low and variable land productivity, and inefficient use of production inputs are major concerns in Mauritania. That prompted this benchmarking analysis of 17 small and 3 large irrigation schemes located along the River Senegal. The objectives were to establish benchmarks for both productivity and performance of irrigation schemes along the valley, and to inquire whether small schemes function better than large schemes. Cluster and data envelopment analyses enabled, respectively, grouping and ranking of irrigation schemes according to a set of pre-determined performance indicators: *viz.* energy costs, relative irrigation supply, irrigation intensity related to irrigable and equipped area, adequacy, and land productivity. Land productivity, which was highly variable, was compared to simulated land productivity for non-limiting conditions in order to determine yield gap variations. Few early sown crops were close to the simulated yield frontier of 10.6 t ha^{-1} and the mean yield was similar for large and small schemes (3.50 t ha^{-1} and 3.77 t ha^{-1}, respectively). The analysis of the indicators revealed that, on average, large schemes performed similarly to small-scale schemes, but small schemes were more variable, particularly in input-use efficiency. Analysis of clusters identified three groups of irrigation schemes: *viz.* consuming and productive, precarious, and productive and economic. According to data envelopment analysis, four irrigation schemes were identified as technically efficient. Their average land productivity was relatively high (4.75 t ha^{-1}) and energy costs were contained (59 € ha^{-1}). Data envelopment analysis also identified the particular efficient schemes that should be taken as reference for improvement of each inefficient scheme.

Keywords: benchmarking; data envelopment analysis; cluster analysis; land productivity; performance indicators

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3.1. Introduction

Since its introduction to Mauritania in the 1970s, irrigated rice has faced innumerable challenges and has not met expectations in terms of irrigated area and yield (Republique Islamique de la Mauritanie, 1999). In response, the World Bank and the Government of Mauritania launched the Integrated Development Program for Irrigation Agriculture in Mauritania (IDPIAM) in 1999. The Program is currently in its second phase. Despite this effort, of a total equipped area of 45,012 ha to 1999, only 22,840 ha remained irrigated in 2004 (FAO, 2005), and the area fell further to 18,328 ha by 2008 (DPCSE, unpublished results). Moreover, although rice yields in West Africa are generally higher than in East- and South-Africa (Nakano et al., 2011), land productivity still represents a main concern in Mauritania for its low and variable yields, with mean value in the range 3–3.5 t ha^{-1} (FAO, 2005). That is well below attainable yields of 8–9 t ha^{-1} recorded at plot level (Haefele et al., 2001).

This situation calls for deeper understanding of the causes of degradation and low productivity of irrigated agriculture in Mauritania, at a time when demand on irrigated agriculture for production, livelihoods, and efficiency of resource use, altogether restricted by increasing competition for public funds, is driving attention towards improving performance of irrigation schemes. Benchmarking, relatively new in the irrigation and drainage sector, is a means by which organisations can improve performance by comparing themselves against others with similar purposes or processes (Malano et al., 2004). The International Water Management Institute (Molden et al., 1998) and the International Programme for Technology and Research in Irrigation and Drainage (Malano and Burton, 2001) have offered crucial contributions to development of comparative performance indicators for benchmarking in irrigation and drainage since the early 1990s.

Malano et al. (2004) emphasise that simple comparison of irrigation schemes using performance indicators may provide an incomplete picture, so other tools are required. Cluster and data envelopment analyses can contribute here because they can assemble performance indicators for clearer interpretation. In this case, cluster analysis segregates irrigation schemes into homogeneous groups defined by common characteristics. Two recent examples demonstrate the power of the method. First, Rodríguez-Díaz et al. (2008) who characterised different irrigation schemes in Andalucía, and Córcoles et al. (2010) who grouped water users associations in Castilla-La Mancha, also in Spain, according to specific performance and energy indicators. By contrast, data envelopment analysis is a non-parametric, linear programming method that works with input/output ratios to calculate relative efficiencies of organisations. This technique has so far had little application in irrigation. Pioneer work has been that of Rodríguez-Díaz et al. (2004a, 2004b) who evaluated efficiency of irrigation schemes in Andalucía according to a set of performance indicators.

In recent years, international attention has again turned towards investment in irrigation in Sub-Saharan Africa (World Bank, 2008). Within this, there is a continuing discussion on whether investments should promote large- or small-scale irrigation (Inocencio et al., 2007; Nakano et al., 2011; Fujiie et al., 2011; Barbier et al., 2011). The present benchmarking analysis pursues this discussion explicitly seeking to answer if small schemes function better than large schemes in the Senegal Valley in Mauritania. A second objective was to establish benchmarks for both productivity and performance of irrigation schemes along the valley. The present paper may thus be useful for policy makers in steering the future course of actions for irrigated rice in Mauritania. Two studies on performance assessment of small (see Chapter 4) and large schemes (see Chapter 5) for rice cultivation in Mauritania form the basis for the benchmarking analysis presented here. It is complemented by the work by Comas et al. (2012) that ranks households according to their efficiency in using inputs and labour in irrigated rice based on their various farming system and yields.

3.2. Materials and methods

3.2.1. Selected irrigation schemes, performance indicators, and field measurements

The study concerns 17 small and 3 large schemes (PPGII, CPB, and M'Pourie) located in the Gorgol, Brakna, and Trarza regions of the Senegal River Valley (Figure 3.1 3.1). Small-scale community-managed and large-scale public irrigation schemes in Mauritania, together, account for a 50 % of the total area equipped for irrigation. Small schemes, 10–100 ha, are located adjacent to the Senegal River from which they distribute water to plots in rudimentary, open, earth channels using small diesel pumps. Each small scheme belongs to a village cooperative that arranges credit and production inputs, and manages irrigation (Diemer and Huibers, 1991; see Chapter 4). Large schemes, 500–2000 ha, are owned by the State and are usually co-managed by the "Société Nationale pour le Développement Rural" (SONADER) and a Board representing constituent cooperatives, although in some cases private companies manage water delivery. In large schemes, water is usually supplied by a central, diesel or electric pumping station, although in one of three large schemes studied here, water is supplied by gravity.

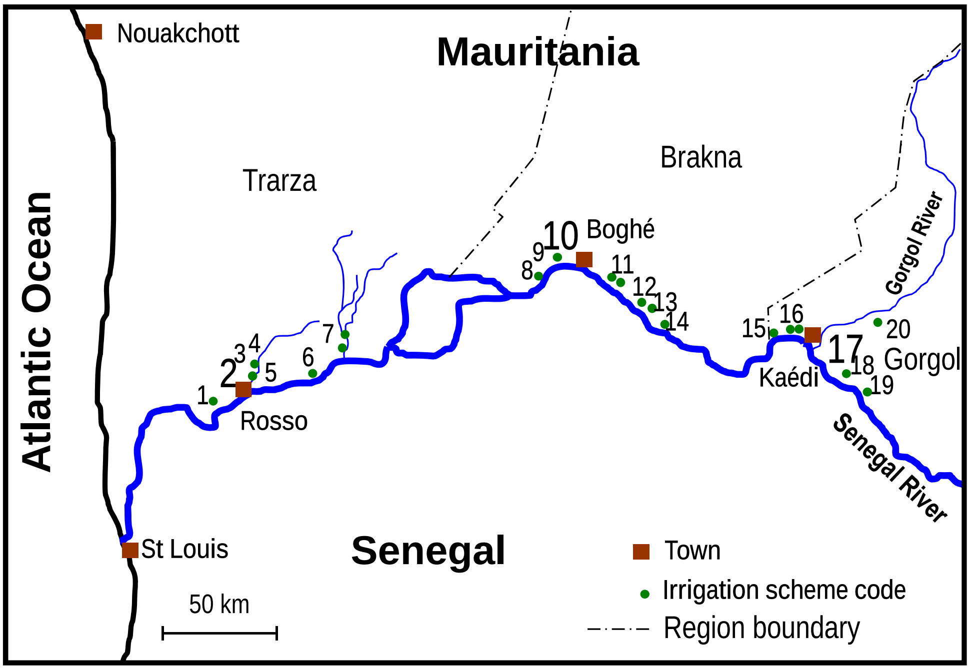

Figure 3.1. Map showing location of the small- and large-scale irrigation schemes studied. Scheme codes correspond with codes in Table 3.1.

External performance indicators generally lend themselves better than internal indicators (i.e., those that describe internal irrigation processes of water distribution) to cross-scheme comparison because internal indicators are usually scheme-specific so data collection is time consuming, expensive, and complex (Molden et al. 1998). Consequently, the present benchmarking analysis focuses on one internal indicator only, adequacy, and on the external indicators: energy cost, relative irrigation supply, irrigation intensity, and land productivity, most of which originate from Bos et al. (2005) and Malano and Burton (2001). Indicators for performance assessment of small and large schemes were taken from García-Bolaños et al. (2011, see Chapter 4) and Borgia et al. (2012, see Chapter 5), respectively.

Energy cost (EC) was calculated as the total cost of diesel, or electricity, consumed during the irrigation campaign per unit irrigated area. Relative irrigation supply (RIS) is the ratio between the total volume of irrigation water supplied and the net volume of irrigation water required by the crop. Irrigation intensity refers to the actual agricultural use of the irrigable (II1) or equipped (II2) area. Adequacy (A) refers to the capacity to meet crop water requirements. Experienced observers assigned scores according to how well the plots were irrigated or drained through comparative evaluations made during field visits (see Chapter 4; see Chapter 5). The value of A was taken as the minimum of irrigation and drainage adequacies. In small schemes, evaluations comprised the whole irrigated area, but in large schemes, A was determined in a sample of cooperatives, 6, 5, and 18 in PPGII, CPB, and M'Pourie, respectively, so that the various physical conditions (i.e., topographical elevation, soil type, and location in the irrigation system) were represented (see Chapter 5). More details on definitions of external indicators and assessment criteria for adequacy can be found in Chapter 4 and Chapter 5.

Land productivity (LP) was expressed as the paddy yield harvested by farmers per unit surface. In small schemes LP was estimated from samples of 10–20 % of the total cropped plots distributed along representative irrigation canals. At harvest, farmers filled sacks of similar size with the paddy rice. Cropped area for each selected plot (or group of adjacent plots belonging to the same farmer) was measured (see Chapter 4), the total number of filled sacks was counted, and between 12–15 % was weighed. [Note that scheme yields reported in Chapter 4 are slightly different to those reported here, being estimated from the number of sacks recorded by the cooperatives and the measured mean weights of filled sack]. In large schemes, paddy yield was measured in every plot (or group of adjacent plots belonging to the same farmer or cooperative) of a sample of tertiary canals belonging to the same sample of cooperatives chosen for the estimation of adequacy. The number of sacks per plot was counted, a minimum of 8 sacks per plot was weighed, and the surface of the sampled plots was measured (see Chapter 5). Altogether, sampled plots covered approximately 10 % of the cultivated surface in each large scheme.

3.2.2. Yield estimated with the Oryza2000 rice model

Two contrasting rice production systems are followed in Mauritania: in Trarza, seed is broadcasted after soil preparation whereas in Gorgol and Brakna rice is transplanted. The potential rice yield of these two systems was estimated by the rice crop model

Oryza2000 (Bouman et al., 2001; Bouman and van Laar, 2006) with the setting of non-biotic and abiotic stresses. Oryza2000 calculates daily assimilation as a function of incoming radiation, temperature, leaf area index, and nitrogen contents. Assimilate allocation depends on development stage, photoperiod, and temperature. Development of the crop depends on ambient temperature and photoperiod. Both low and high temperatures have adverse effects on the number of spikelets and their fertility. In this study, potential grain yield of both systems was simulated for 9 sowing dates at 15-day intervals starting on June 1^{st} using long-term average climate data from Rosso and Kaedi (Figure 3.1) and local soil characteristics (Verheye, 1995).

3.2.3. Hierarchical cluster analysis (HCA)

The hierarchical cluster analysis (HCA) applied here groups individual cases (i.e., the irrigation schemes) together according to Euclidean distance that separates them (Ward, 1963), defined by a set of pre-selected variables, *viz*. performance indicators. HCA is a stepwise process that starts with each case representing a cluster of its own and follows with a sequential pairing of cases or previously formed clusters separated by minimum distance. The process can continue until all clusters have merged, so the appropriate number of clusters is chosen according to the circumstances and objectives of the analysis (Romesburg, 2004).

The performance indicators used in HCA were A, II1, II2, LP, EC, and RIS. Since one objective of the analysis was to compare the performance of small and large-scale schemes together, the variables "equipped area" and "number of active farmers" were excluded from the analysis. To include them would discriminate schemes according to size with consequent formation of one group composed of the three large schemes only. Performance indicator values were standardised prior to analysis. HCA was carried out using R, a language and environment for statistical computing (R Development Core Team, 2010).

3.2.4. Data envelopment analysis (DEA)

Technical efficiency (TE) measures the ability of a decision-making unit (DMU) to produce optimal output from a given set of inputs. The analysis presented here adopts variable returns to scale because agricultural activity rarely operates in perfect market conditions in which increased inputs always correspond to increased yields.

Input-oriented TE evaluates which input quantities can be reduced without changing the output quantities produced; whereas output-oriented TE reverses the question, i.e., how much can output quantities be augmented without altering input quantities. In the benchmarking analysis of Andalusian irrigation schemes, the concern of Rodríguez-Díaz et al. (2004a) was how efficient DMUs (irrigation schemes in this case) could use water and energy. For this, they appropriately adopted an input-oriented approach. In the present analysis, however, where low productivity is the major concern, an output-oriented approach was adopted to identify conditions that promote higher yields.

DEA estimates TE of a given set of DMUs using as reference the best performing ones in terms of use of inputs and production of outputs. Compared to parametric, efficient-frontier methods, DEA does not require a pre-determined production function, a clear advantage when benchmarking performance of irrigation schemes (Malano et al., 2004). In DEA, the frontier function is constructed using virtual units that are weighted combinations of observed most efficient DMUs; TE of inefficient DMUs is then calculated as the relative distance from the frontier function (Coelli et al., 2005). Figure 3.2 shows the frontier function constructed for the case of two inputs and one output. The axes represent the ratios between each input and the output. The convex shape of the efficient-frontier is specific of the output-oriented approach. A', B', C' represent virtual efficient DMUs that contribute to the construction of the frontier, whereas B is an actual inefficient DMU. The TE of unit B is then calculated as TE=0B'/0B, whereby B' represents the virtual reference unit for B. Thus, for each inefficient DMU, DEA also identifies the weight of the actual efficient DMUs contributing to the virtual DMU acting as reference.

A detailed description of the processes used by DEA can be found in Coelli et al. (2005). DEA was performed using the free software DEAP 2.1 (Coelli, 1996).

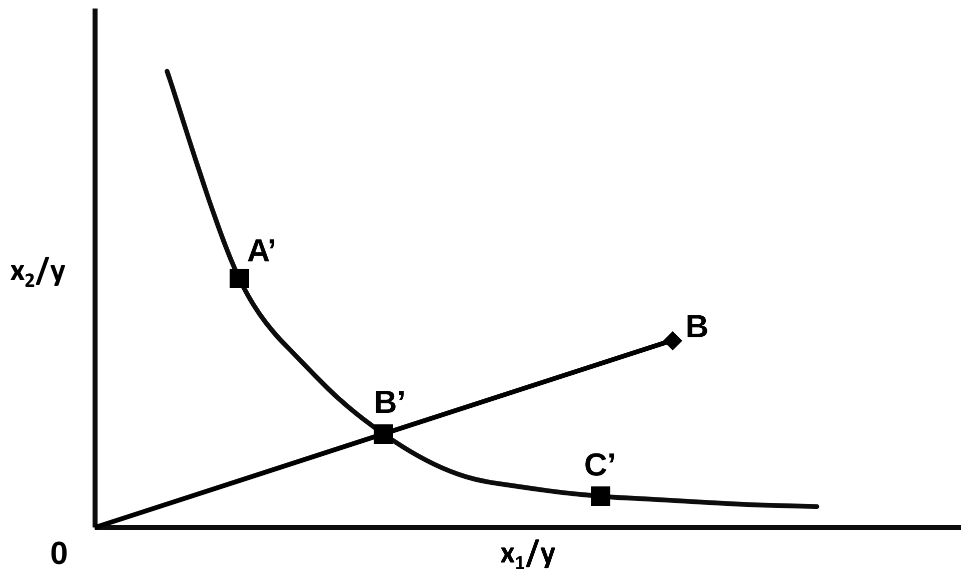

Figure 3.2. Efficient-frontier function for the case of two inputs and one output. The axes represent the ratios between each input (x_1 and x_2) and the output (y). A', B', C' represent virtual efficient decision making units that contribute to the construction of the frontier. B is an actual inefficient decision making unit.

3.3. Results

3.3.1. Yield and yield gap

The global average yield of all schemes was 3.73 t ha^{-1} and average yield of large and small schemes was similar (Table 3.1). However, high variability was observed both among and within schemes. Cooperatives cultivating in large schemes had average yields varying from 1.69 to 4.80 t ha^{-1} (Figure 3.3), a comparable range to that of small schemes: 1.34 t ha^{-1} to 5.74 t ha^{-1} (Figure 3.4). Absolute minimum and maximum plot yields were, respectively, 0.44 and 9.75 t ha^{-1} in small schemes (Figure 3.4), and 0.40 and 8.82 t ha^{-1} in large schemes (Figure 3.3). The mean range between greatest and smallest plot yields within cooperatives was 3.43 and 3.47 t ha^{-1} for large and small schemes, respectively.

Yields in small schemes in Trarza, the region adjacent to the coast, tended to be greater than in the interior (Brakna and Gorgol) (Figure 3.4): average yield 4.56 vs. 3.34 t ha^{-1}. However, highly productive schemes were observed in the three regions. Yield in

Table 3.1. Performance indicators of large- and small-scale irrigation schemes. Values of small-scale and large-scale schemes refer to the irrigationcampaigns 2008 and 2010, respectively. EC: energy cost; RIS: relative irrigation supply; A: adequacy; II2: irrigation intensity referred to equipped area; II1: irrigation intensity referred to the irrigable area; LP: land productivity; DIC: day of year of initiation of campaign.

Scheme	Code	Region	EC (€ ha^{-1})	RIS	A	II2	II1	LP (t ha^{-1})	DIC
Breun Goyar	1	Trarza	97.8	2.02	0.75	0.74	0.97	5.74	190
Garak 2	3	Trarza	99.3	1.85	0.5	0.77	0.84	4.85	211
Garak 3	4	Trarza	66.9	1.25	0.75	0.87	0.94	4.4	217
Tendagha	5	Trarza	53.6	1.18	0.38	0.96	0.96	4.04	204
Sattara	6	Trarza	67.7	1.51	0.25	0.52	0.61	3.42	222
Kéké	7	Trarza	54	1.44	0.58	0.59	0.67	4.9	203
Tobeit	8	Brakna	77.8	1.08	0.33	1	1	4.63	185
Bakaho	9	Brakna	183.2	2.02	0.5	0.64	0.98	3.42	192
Dagveg	11	Brakna	38.3	1.18	0.83	0.96	0.96	3.62	186
Wabounde	12	Brakna	109.9	1.8	0.58	0.97	0.99	3.83	197
Sare Souki	13	Brakna	62.4	0.99	0	0.34	0.54	1.34	206
Aere M'Bara	14	Brakna	138.9	2.66	0.75	0.27	0.46	2.25	226
Rindiaw-Silla	15	Gorgol	92.7	0.82	0.88	0.72	0.72	3.05	210
Bélinabé	16	Gorgol	114.2	1.9	0.08	0.14	0.18	2.49	204
Djeol 1	18	Gorgol	118.5	1.77	0.58	0.65	0.71	3.77	208
Djeol 2	19	Gorgol	63.2	0.92	0.38	0.62	0.77	2.62	225
Caldi Endam	20	Gorgol	104.6	2.13	0.42	0.66	0.78	5.72	197
MEAN SMALL			**90.8**	**1.56**	**0.5**	**0.67**	**0.77**	**3.77**	**205**
M'Pourie	2	Trarza	56.3	2.89	0.61	0.69	0.85	3.15	
CPB	10	Brakna	48.4	3.25	0.67	0.91	0.98	3.63	
PPGII	17	Gorgol	*7.5	*0.79	0.69	0.83	0.88	3.72	
MEAN LARGE			**37.4**	**2.31**	**0.66**	**0.81**	**0.9**	**3.5**	
MEAN ALL			**82.8**	**1.67**	**0.53**	**0.69**	**0.79**	**3.73**	

*these values do not include irrigation water supplied to the system by gravity

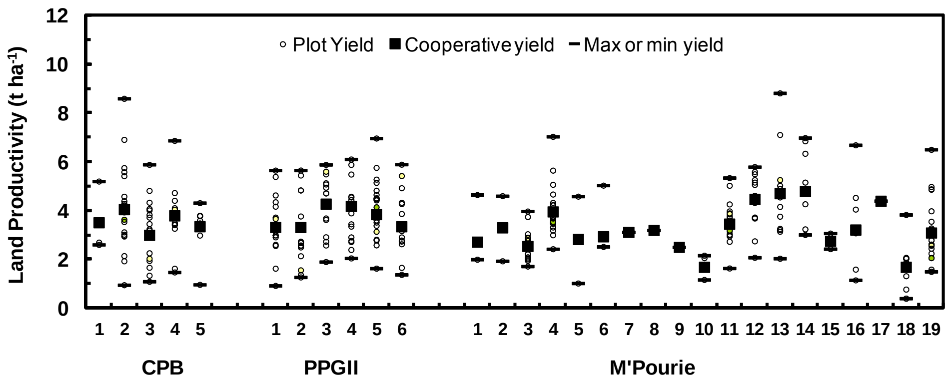

Figure 3.3. Plot yield, minimum and maximum plot yield in each cooperative, and mean cooperative yield of the studied cooperatives (numbered in the abscissa) in the three large-scale irrigation schemes.

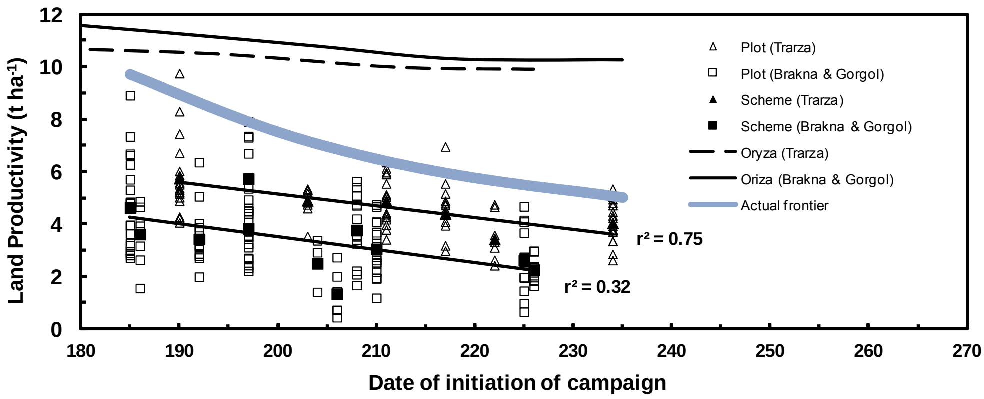

Figure 3.4. Land productivity vs. date of initiation of the irrigation campaign (expressed as day of the year) for the small-scale schemes studied: Oryza2000 model yield frontier for direct seeded rice in Trarza and transplanted rice in Brakna and Gorgol; plot and scheme yields in Trarza, Brakna and Gorgol; approximated plot yield frontier; and regression lines of scheme yields for Trarza, Brakna, and Gorgol.

small schemes was related to some extent to the start of season (Figure 3.4): around 50 kg ha^{-1} decrease per day of delay after July 4th (day of year 185) in both regions, next to the estuary and in the interior. The approximate plot yield frontier is included in Figure 3.4 for comparison. This frontier decreases more rapidly with timing of initiation of campaign than the straight lines fitted to the measured scheme yields. Yield *versus* date of initiation of campaign was only analysed in small schemes because comparable information on planting dates in large schemes was not available.

Yield variation related to campaign delay was examined using the rice crop model Oryza2000 simulating crop yield of direct sown rice in Trarza and transplanted rice in Gorgol. The simulated yield frontier was around 10.6 t ha^{-1} in Trarza and Gorgol (Figure 3.4). This is almost 1 t ha^{-1} greater than the best yielding plot but defines a large yield gap when compared with the remaining plots, particularly in later sowings. The model simulated somewhat higher yield for transplanted rice in Brakna and Gorgol than for direct sown crops in Trarza. It also predicted a slight yield decrease with planting date in both systems, 26 and 18 kg d^{-1} delay, respectively. This is about half the penalisation observed in the actual yield data and about one fourth the penalisation indicated by the actual plot yield frontier.

3.3.2. Grouping of the irrigation schemes

The values of performance indicators used in HCA, viz. A, II1, II2, LP, EC, and RIS, are presented in Table 3.1. Like LP, the rest of indicators varied widely among schemes, particularly EC and A. From the dendrogram obtained by HCA (Figure 3.5), it appears reasonable to adopt a solution of 3 clusters. Cluster 1 is characterised by irrigation schemes with low LP (2.42 t ha^{-1} on average) and II1 and extremely low A (< 0.40 in all schemes but Aere M'Bara, Table 3.2) and II2 (Table 3.2). Aere M'Bara and Bélinabé joined this group at a later stage (Figure 3.5) and, in contrast to the rest of this group, had high EC and RIS. On the other hand, main features of cluster 2 (Figure 3.5) were relatively high yields (3.91 t ha^{-1} on average) while using least water and energy (Table 3.2). RIS values were close to unity, expressing an efficient use of water. Irrigation intensities were also very high (Table 3.2). Cluster 3 had highest average LP (4.33 t ha^{-1}) yet on average used more water and energy than the other two clusters. This cluster, comprising a larger number of schemes, showed expectedly the largest intragroup variance with respect to EC and LP. Standard deviations were respectively 42 € ha^{-1} and 0.99 t ha^{-1}, Table 3.2).

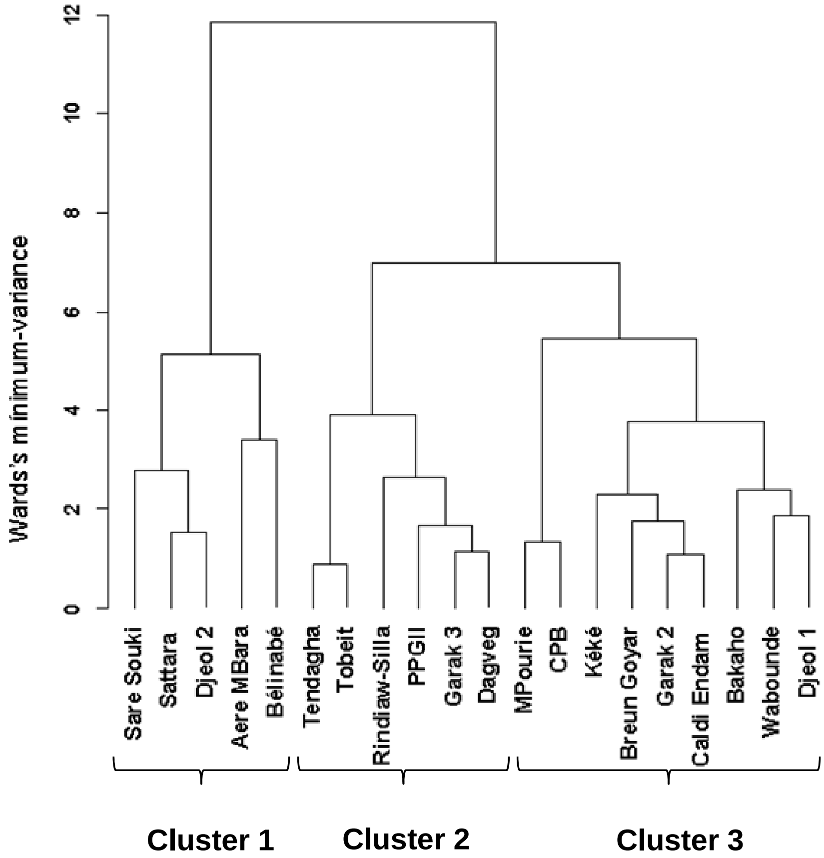

Figure 3.5. Dendrogram of clusters of irrigation schemes.

Table 3.2. Mean value and standard deviation of performance indicators in the three established clusters. EC: energy cost; RIS: relative irrigation supply; A: adequacy; II2: irrigation intensity referred to equipped area; II1: irrigation intensity referred to the irrigable area; LP: land productivity.

Performance Indicators	Cluster 1		Cluster 2		Cluster 3	
	Mean	StDev	Mean	StDev	Mean	StDev
EC (€ ha^{-1})	89	35	56	30	97	42
A	0.29	0.3	0.64	0.23	0.58	0.1
RIS	1.6	0.72	1.05	0.20	2.13	0.58
II2	0.38	0.19	0.89	0.1	0.74	0.13
II1	0.51	0.22	0.91	0.1	0.86	0.12
LP (t ha^{-1})	2.42	0.75	3.91	0.57	4.33	0.99

3.3.3. Technical efficiency

The performance indicators included in DEA result from preliminary analyses that eventually led to selection of two inputs, EC and RIS, and one output, LP. In this way, a scheme that uses relatively little water, implying low cost of energy while achieving higher yields with respect to other schemes, is considered efficient. A first series of analysis also included II1 as second output. The result was however less discrimination among schemes because TE increased in all irrigation schemes. This is interpreted as an artefact of the DEA model and the way it constructs the efficient-frontier when using a multi-stage method for analysing variable returns of scale (Coelli, 1996).

TE of each DMU is presented in Figure 3.6. Four irrigation schemes (Breun Goyar, Kéké, Tobeit and PPGII) were identified as technically efficient and used to construct the efficient-frontier. Their average yield was relatively high (LP= 4.75 t ha^{-1}) and energy costs were contained (EC= 59 € ha^{-1}).

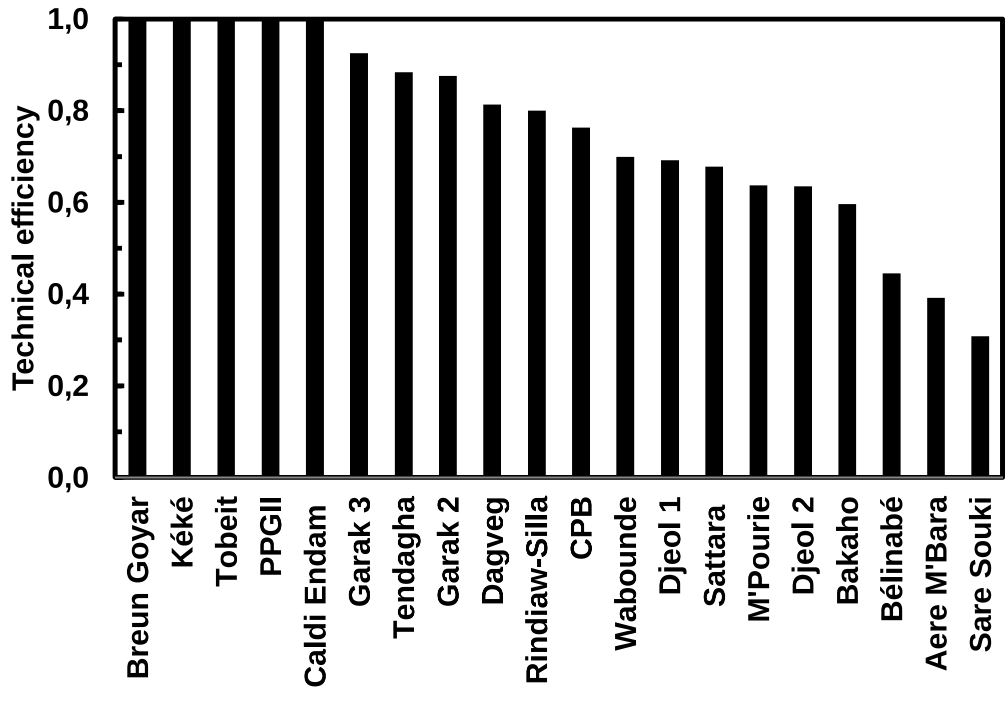

Figure 3.6. Technical efficiency of the irrigation schemes studied, based on data envelopment analysis.

In PPGII, cost of energy per unit of area was exceptionally low (EC= 7.5 € ha^{-1}) because, there, whenever water levels in the Gorgol river (a tributary of the Senegal river) rise above 10 m asl, this scheme can irrigate by gravity (see Chapter 5). This also explains why the scheme appears in the efficient-frontier. Irrigation systems of Breun and Tobeit were in relatively good condition and irrigation was effectively managed by the community of water users, which assured reliable and adequate supplies of water to plots. Although Breun presented a relatively high RIS, it had the highest crop yield (LP= 5.74 t ha^{-1}). The least efficient systems, by contrast, were severely deteriorated (Sare Souki and Aere M'Bare), badly rehabilitated (Bélinabé), or with highly unreliable pumps (Sare Souki) (see Chapter 4). These contributed to inadequate water supplies and low yields, which averaged 2.03 t ha^{-1} in these irrigation schemes, while (average) energy costs in Aere M'Bara and Bélinabé exceeded 110 € ha^{-1}.

Figure 3.7 shows the relative weight of actual efficient schemes in composing the virtual units acting as reference for inefficient schemes to move to the efficient-frontier. For instance, Breun and Tobeit are the references for improving efficiency in Djeol 1, with relative weights of 0.7 and 0.3, respectively (Figure 3.7). Tobeit was the scheme that served most times as reference for the improvement of inefficient schemes, the so-called "global leader".

3.4. Discussion

With irrigation development reappearing on the international agenda in recent years (Fujiie et al., 2011), there is much debate on whether the focus should be on small- or large-scale irrigation (Inocencio et al., 2007; World Bank, 2008; Barbier et al., 2011; Nakano et al., 2011). According to the analyses performed in this paper, there was no evidence for better performance of one type of scheme. Large-scale schemes (PPGII, CPB, and M'Pourie) were scattered over a wide efficiency range according to DEA (Figure 3.6). Although they did form part of the "productive" clusters (2 and 3,Figure 3.5), only PPGII was included among the most efficient schemes. Small schemes were both the most and the least efficient, revealing that cooperative-based management introduces more variability than the state-cooperative management of large schemes.

If costs of investment are included in evaluation of performance, then, as Inocencio et al. (2007) argued, small schemes do better than large schemes. However, in terms of use of land, water, and energy, large-scale schemes have similar technical efficiencies as small schemes in Mauritania. This supports Nakano et al. (2011), who evaluated the contribution of large schemes to a green rice revolution in Sub-Saharan Africa. They reported that given reliable access to water, large-scale irrigation has great potential and offers good returns to investment.

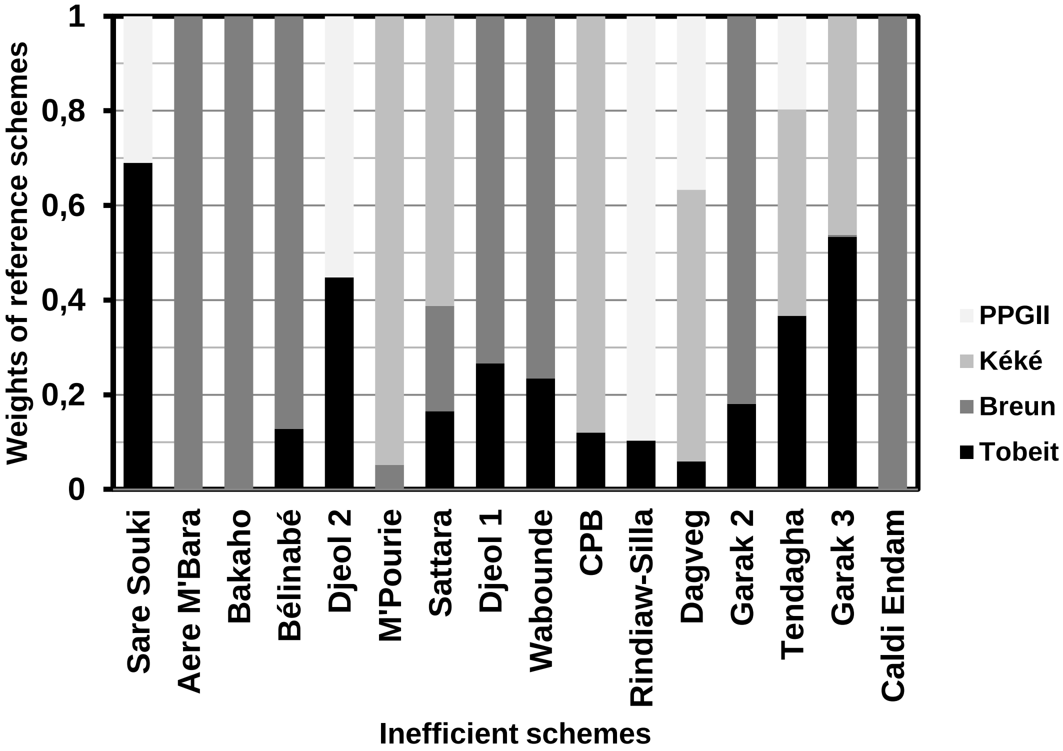

Figure 3.7. Relative weight of the four efficient irrigation schemes referenced to inefficient schemes.

Neither scale (small vs. large) nor management (community vs. state) had any influence on crop yield. Yield variability and yield gap were great in both small and large schemes (Figure 3.3 and Figure 3.4). These findings suggest that productivity of irrigation in Mauritania could be improved substantially –a conclusion supported by many advocated causes of rice yield gap in the Senegal River Valley. These include: sub-optimal timing of weeding (Poussin et al., 2003); inadequate use of fertilisers (Wopereis et al., 1999; Haefele et al., 2001, 2004; Poussin et al., 2003); transplanting of old seedlings (Wopereis et al., 1999; García-Ponce et al., 2012); poor quality of water delivery service (see Chapter 4); and inadequate drainage (see Chapter 5). This study showed that delaying initiation of the irrigation campaign might exacerbate other contributing causes of rice yield gap in Mauritania. Mean yields in small schemes in Trarza were usually greater than in Brakna and Gorgol (4.56 vs. 3.34 t ha^{-1}), consistent with observations of Comas et al. (2012). Results are also consistent with greater solar radiation in Trarza but contrary to expected lower yields in direct seeded rice compared to transplanted systems in Brakna and Gorgol (Dingkuhn, 1995; Cabangon et al., 2002; Poussin et al., 2003; McDonald et al., 2006). Farmers in Brakna and Gorgol seem to lose their advantage against direct seeding because transplanting is often delayed beyond recommended seedling age (García-Ponce et al., 2012).

In 13 out of 20 irrigation schemes analysed, average productivity fell below the break-even yield of 4 t ha^{-1} required to cover full production costs, including amortisation of irrigation equipment (Comas et al., 2012). While various studies agree on the high potential for rice yields in the Senegal River Valley under favourable circumstances (Otsuka and Kalirajan, 2006; Nakano et al., 2011), existing socioeconomic constraints seem to discourage farmers to produce higher yields (Crousse et al., 1991; Poussin and Boivin, 2002) and to engage in collective action directed to improve the quality of the water delivery service (Vandersypen et al., 2008; see Chapter 4).

Despite sharing numerous similarities in terms of infrastructure, irrigation management, crop, and production inputs, the study revealed large differences in performance indicators (Table 3.1) and in technical efficiency among irrigation schemes (Figure 3.6). Mean values for the performance indicators defining each cluster suggest a classification of the irrigation schemes into: precarious (cluster 1); productive and economic (cluster 2); and consuming and productive (cluster 3). Precarious schemes had severely deteriorated irrigation systems and unreliable water provisions. The disrepair of irrigation networks had repercussions on A which, in turn, reduced LP and/or led to the partial abandonment of land (Belinabé and Aere M'Bara). Physical degradation was often caused by poor quality in design and/or construction (Mateos et al. 2010) and was exacerbated by the absence of adequate maintenance rules or liquidity to carry out major works (see Chapter 4).

Schemes of cluster 1 also occupied the tail end of the efficiency ladder in the DEA, denoting coherence between the two methods of analysis. By contrast, irrigation and drainage infrastructures of cluster 2 were in relatively good state (4 of 6 schemes had recently been rehabilitated), contributing to low consumption of water and energy. Consuming and productive schemes of cluster 3 were heterogeneous in EC and LP, which is reflected by the large spectrum of efficiency values in the DEA (Figure 3.6). In fact, all these schemes worked at decreasing returns to scale, particularly for energy cost. This signifies that the same yield could be obtained with considerably smaller cost of pumping, which alone represented 30 % of the total production costs (see Chapter 4; Comas et al., 2012). In Bakaho, for instance, energy costs per unit area were more than twice those of Tobeit, the “global leader”, and fivefold those of Dagveg, the least consuming scheme in terms of energy (except PPGII, where irrigation was by gravity during two months). This points to mismanagement of both pumping station and irrigation scheduling, and once again reinforces the importance of improved collective decision making (Poussin et al., 2006) and training of skilled personnel (Vandersypen et al., 2006; Mateos et al., 2010).

Nevertheless, existing variability and the performance gap between schemes are positive signs that improvement is possible. DEA offers interesting directions for improvement by identifying the best performing schemes (three small schemes, Breun Goyar, Kéké and Tobeit; and a large scheme, PPGII) and which of them can inefficient schemes emulate for improvement (Figure 3.7). Tobeit served most frequently as a reference probably because it has the closest to optimum RIS and represents an example of good irrigation management. PPGII had the lowest cost of energy per unit of area but so extremely low that inefficient schemes may consider Kéké to be a more feasible reference to reduce costs. Of course, any increase in crop yield while maintaining similar inputs will also increase efficiency**.**

The study sample of small schemes represented 16.5 % of their total irrigated area during the 2008 campaign (see Chapter 4) while for large schemes the area was significantly higher (50 %). This shows that this study provided a representative picture of performance of irrigated rice in Mauritania, its shortcomings and opportunities, and therefore offers useful paths for the improvement of the various groups of irrigation schemes.

3.5. Conclusions

Yield and technical efficiency were extremely variable in irrigation schemes along the Senegal valley in Mauritania; however, both DEA and HCA showed that there were some productive and efficient schemes. Comparison of small- and large-scale irrigation schemes showed that, on a pure technical basis, large schemes did not perform worse than small schemes. However, small schemes showed greater variability, which may indicate a larger margin for improvement and also existence of successful schemes.

A new policy that incentivises farmers' participation in irrigation improvement could use specific efficient schemes as benchmarks for each inefficient scheme. Then, study tours, lessons exchanges, and information flow would become most effective means for their enhancement.

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Chapter 4

Performance assessment of small irrigation schemes along the Mauritanian banks of the Senegal River

4. Performance assessment of small irrigation schemes along the Mauritanian banks of the Senegal River[1]

Abstract

Irrigation plays a fundamental role in world food provision but, to date, it has performed below expectations in Sub-Saharan Africa. The present study assesses and diagnoses the performance of 22 small and medium size community-managed irrigation schemes, mainly devoted to rice production, in different locations along the Mauritanian banks of the Lower Senegal River. The evaluations followed the Rapid Appraisal Process in which semi-structured interviews were held with representatives of the Cooperatives' Boards in charge of each scheme to obtain information about the organisation of the cooperative, land tenure, irrigation system and organization, cropping pattern and soils. Additionally, for each irrigation scheme, the water-delivery service was characterized by making qualitative and comparative observations during field inspections; the pumping station's performance was diagnosed by a local specialist; the discharge at the head of the system was measured; daily irrigation time was recorded; and crop yields were determined by plot sampling. Then a set of performance indicators was computed. Water delivery capacity referred to irrigated areas was insufficient in a third of the schemes, and this insufficiency was exacerbated by poor maintenance. Irrigation intensity in habilitated areas was rather low being less than 0.66 in 50 % of the schemes. The average productivity of land, irrigation water, and fuel (3.38 t ha^{-1}, 0.30 kg m^{-3} and 2.37 kg kWh^{-1}, respectively) were well below potential.

Keywords: community-managed irrigation scheme; water delivery service; water productivity

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4.1. Introduction

Reviews of studies in Asia and Africa have concluded that, overall, irrigation contributes to poverty alleviation by enhancing productivity and promoting economic growth and employment (Hussain and Hanjra, 2003; Hussain and Hanjra, 2004; Namara et al., 2010). It also has linkages and complementarities with education, health, and social equity (van den Berg and Rubens, 2006; Hanjra et al., 2009). Irrigation has thus been credited in many Asian countries as the springboard out of poverty.

Given that irrigation will continue to play a fundamental role in global food provision –although investment in irrigation is unlikely to continue at the same level as in the recent past (FAO, 2003)–, some new projects are still foreseeable in Sub-Saharan Africa (SSA). Conversely, it is in SSA where irrigation has so far failed to impel development (Inocencio et al., 2006). Future investments there will need to precisely target specific needs in specific niches (Turral et al., 2010), and will have to learn carefully from past failures in order to avoid their recurrence. As opposed to large irrigation systems, small irrigation schemes are a priority for current irrigation policies in SSA as they combine features aimed at ensuring food security, settlement success, and the integration of cultural traditions (Turner, 1994; Vincent, 1994; Faurès et al., 2007).

Mauritania is one of the world's poorest countries. Over 80 % of its land surface (1,030,700 km^2) is desert. Arable land is scarce, and, except for some oases, agriculture is limited to a narrow band along the Senegal River where most of the country's food production is concentrated.

After irrigation was introduced in the Senegal valley in the 1970s, it expanded in the late 1980s following the construction of two dams: the Diama dam in the river delta, to prevent the intrusion of salty water during periods of low discharge, and the Manantali dam in the upper part of the basin, which regulates approximately 50 % of the total river discharge.

The impact of the Manantali dam on traditional agriculture has been serious (United Nations/World Water Assessment Programme, 2003). For centuries, the annual floods of the Senegal River have been the basis for flood recession agriculture, but the dam of Manantali has reduced these floods and impaired the associated agricultural production method. Moreover, irrigated area has decreased since the mid-1990s: in 1994, the irrigated area was 40,261 ha; by 2004, this had fallen to 22,840 ha (FAO, 2005), and it fell further to 18,326 ha by 2008 (DPCSE, 2009). Of the area irrigated in 2008, 11,595 ha belonged to private schemes, 3,393 ha to large public schemes, and 3,340 ha to small and medium size community-managed schemes (DPCSE, 2009).

Aware of the critical situation derived from the degradation of irrigated agriculture in the valley, but believing in its potential to contribute to food security and rural development, the Government of Mauritania and the Wold Bank, have established an Integrated Development Program for Irrigation Agriculture in Mauritania (IDPIAM). Clearly, a diagnosis of the actual irrigation performance, based on a systematic performance assessment, is imperative.

The numerous variables that influence irrigation (system design, soil and climate, operation, maintenance, socio-economic and institutional settings) make performance assessment a complex task. However, if we focus on commonalities, it should be possible to assess and compare irrigation performance in different settings (Molden et al., 1998). With the aid of appropriate indicators, performance may be quantified and the state of irrigation schemes objectively defined (Molden and Gates, 1990; Bos et al., 2005). More informal survey methods, such as rapid (Carruthers and Chambers, 1981) and participatory (Chambers, 1994) rural appraisal, which combine measurements with direct observations and farmers and irrigation managers interviews, may provide additional understanding of irrigation performance constraints and potentials (Tesfai and de Graaft, 2000).

The objective of the present study was to assess the performance of small and medium size community-managed irrigation schemes along the Mauritanian side of the Lower Senegal Valley using a combination of conventional performance indicators and rapid rural appraisal approaches.

4.2. Irrigation environment in the Lower Senegal Valley

The climate in the Lower Senegal Valley is of Sahelian type, with three main seasons: humid and hot from July to October, dry and warm from November to February, and dry and hot from March to June. The rainy season extends from mid-June to mid-October. Table 4.1 presents some important climatic variables at Rosso (16° 40' N, 15° 45' W) and Kaédi (16° 09' N, 13° 30' W), which are cities located at the western and eastern extremes, respectively, of the study area (Figure 4.1).

Table 4.1. Mean monthly rainfall, reference evapotranspiration (ET_o), and maximum and minimum temperatures at Rosso (16 40' N, 15 45' W) and Kaédi (16 09' N, 13 30' W).

Month	Rain (mm)		ET_o (mm)		Max. temp. (ºC)		Min. temp. (ºC)	
	Rosso	Kaédi	Rosso	Kaédi	Rosso	Kaédi	Rosso	Kaédi
January	3	2	198	201	31.6	31.7	15.2	17.3
February	1	2	210	209	34.5	34.8	16.8	19.6
March	0	0	271	263	36.8	37.7	18.0	21.9
April	0	0	289	275	38.7	40.4	19.0	24.6
May	0	1	307	293	40.2	42.0	20.7	27.1
June	6	17	258	259	39.1	40.6	22.7	27.0
July	39	75	209	215	36.4	37.1	23.9	25.8
August	90	103	178	173	35.6	35.2	24.6	25.3
September	71	80	170	155	36.2	35.7	24.7	25.3
October	20	16	197	176	38.2	37.9	23.4	25.2
November	0	1	182	180	36.0	36.2	19.7	22.0
December	1	1	182	190	32.2	32.5	16.3	18.5
Sum/Mean	231	298	2651	2589	36.3	36.8	20.4	23.3

Traditionally, cropping systems of a typical village in the valley include: extensive grazing, mostly for goats and sheep; pockets of fenced rain-fed cropping (with millet and cowpea as main crops), called *dieri*; flood recession cropping (with sorghum the main crop) on the river edge and floodplain, called *oualo*; and irrigation.

The amount of available water for irrigation is not constrained, as the potential area for irrigation on the Mauritanian side of the valley has been evaluated at 136,500 ha (FAO, 2005). Irrigation is mainly devoted to rice production, which is mostly cropped during the rainy season (July to November) and to a lesser extent during the dry hot season (March to June); thus typically only one rice crop is grown each year in a given plot.

The soil pattern in the Lower Senegal valley is determined by the successive sedimentation of suspended material in the floodwaters. The main soil characteristics are related to the duration and periodicity of these floods and to the micro-topography of the stream-bed (Verheye, 1995). Irrigated soils are deep, with high clay content. The lowest areas in the floodplains are characterized by soils with clay contents exceeding 60 %, which behave as *vertisols* having very low permeability and high water holding capacity. Slightly more elevated areas in the floodplains have somewhat lighter soils (50−60 % clay), with high water holding capacity and easier drainage (Verheye, 1995).

The former types of soil (locally named “hollaldé”) are suitable for rice cropping; the latter (locally named “fondé”) are more suitable for crops other than rice (sorghum and cowpea).

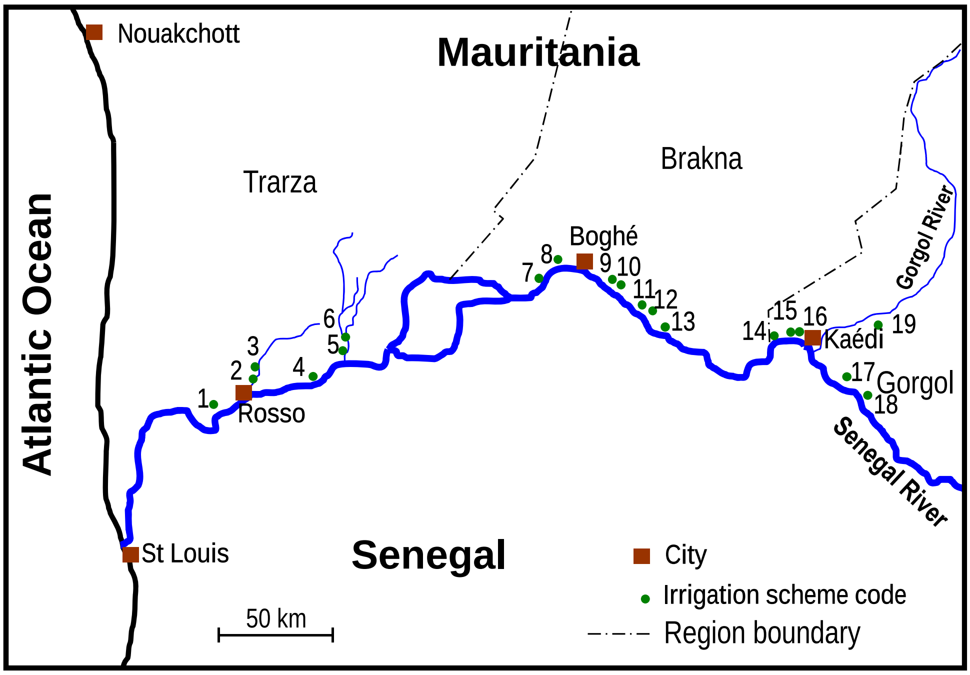

Figure 4.1. Location of the studies irrigation schemes.

4.3. Materials and methods

4.3.1. Sampling small and medium size community-managed irrigation schemes

The criteria for selecting the small and medium size community-managed irrigation schemes included in this study were their representativeness (they should cover the range of sizes present in the study area), their geographical distribution (similar number of schemes in each of the three administrative regions of the study area), and their accessibility during the rainy season. The selection was based on the latest 2006 inventory of irrigation schemes (DPCSE, 2007) and on exploratory visits carried out in June and July 2007. The final studied sample was composed of 22 schemes. Their locations are indicated in Figure 4.1 and their main characteristics are presented in Table 4.2. The sample covered about 16.5 % of the irrigated area of small and medium size community-managed irrigation schemes that engaged in the 2008 campaign.

The irrigated area of the selected irrigation schemes ranged between 10.6 ha and 72.8 ha, with plot sizes between 0.1 and 0.8 ha, and global average plot size of about 0.36 ha.

Each scheme had between one and four pumps that supplied the schemes with water from the Senegal River Table 4.2. The distribution systems were composed of open, unlined canals, although some low-pressure pipes were used in some schemes. All schemes were organised as cooperatives, governed by a Cooperative Board and the General Assembly.

4.3.2. Data collection: rapid appraisal process

The Rapid Appraisal Process (RAP) for irrigation schemes is a quick method that allows qualified personnel to collect and analyse data, both in the office and in the field (Burt and Styles, 1999; Burt, 2002). The process analyses external inputs, such as water supplies, and outputs (e.g. evapotranspiration and yield). Furthermore, it consists of a systematic examination of the equipment, structures and processes used to convey and distribute water within a scheme. With the information gathered, external and internal performance indicators are computed. Internal indicators quantify the performance of internal processes in the irrigation schemes (their water delivery service). External indicators are used to relate outputs from the irrigation scheme derived from the inputs into that scheme, thus they are appropriate for cross-scheme comparison (Molden et al., 1998).

The RAP approach used in the present study considered technical, institutional, financial and organisational aspects of the irrigation schemes. Since some data were sparse, additional data were acquired when necessary.

Data collection began for each irrigation scheme with a semi-structured interview with representatives of the scheme’s Cooperative Board, usually including the president and secretary of the board, and the irrigation organiser. The interviews sought details about the organisation of the cooperative; the history of the scheme and the cooperative; the size and number of plots in the scheme; the number of members in the cooperative; cropping patterns; soil types; the number, type, operation, and state of conservation of pumps; water distribution rules; organisation of canals’ maintenance; credit and financial aspects; and the state of land tenancy and titles.

The interviewers then inspected the irrigation scheme accompanied by the irrigation organisers, pump keepers and ditch riders, who helped in the understanding of any constraints that prevented the proper operation and maintenance of the scheme, and in the identification of critical zones of the irrigation scheme with respect to the soil type

Table 4.2. Main characteristics of the irrigation schemes studied in the 2008 irrigation season.

Scheme	Region	Irrigated area (ha)	No. of active farmers	Plot sizes (ha)	Last intervention (year)	Farmer's Gender	Farmer's ethnic group	Main crop	No. of pumps	Code
Breun Goyar	Trarza	62.3	45	0.4,0.6, 0.75	2006	Male	Wolof	Rice	2	1
Garak 1	Trarza	0*	34	0.35, 0.40	1978	Male	Wolof	Rice	2	2
Garak 2	Trarza	51.9	52	0.3, 0.40, 0.60, 0.80	1978	Male	Wolof	Rice	2	2
Garak 3	Trarza	42.2	47	0.3, 0.40, 0.60, 0.80	2004	Male	Wolof	Rice	2	2
Tandagha	Trarza	22.1	92	0.2	2006	Female	Black moor	Rice	1	3
Sattara	Trarza	28.7	27	0.50, 0.35	1999	Male	Black moor	Rice	2	4
Thiambène	Trarza	0*	33	0.10−0.25	1987	Male	Wolof	Rice	1	5
Kéké	Trarza	23.1	43	0.32	1988	Male	Haalpoulaar	Rice	1	6
Tobeit	Brakna	44.9	101	0.25, 0.50	2006	Male	Black moor	Rice	2	7
Bakaho	Brakna	29.3	83	0.55	1982	Male	Haalpoulaar	Rice	1	8
Dagveg	Brakna	21.5	45	0.50	1989	Male	Black moor	Rice	1	9
Wabounde	Brakna	72.8	162	0.2, 0.32	2006	Male	Black moor	Rice	4	10
Sare Souki	Brakna	16.1	40	0.50	1991	Male	Haalpoulaar	Rice	1	11
Aere M'Bara	Brakna	10.6	42	0.20	1990	Male	Haalpoulaar	Rice	1	12
Dioude Dieri	Brakna	0*	50	0.20	2000	Male	Haalpoulaar	Rice	1	13
Sinthiou	Gorgol	16	55	0.25	1972	Male	Haalpoulaar	Sorghum	1	14
Rindiaw-Silla	Gorgol	40.6	94	0.50	2000	Male	Haalpoulaar	Rice	2	15
Bélinabé	Gorgol	20	45	0.40	2006	Male	Haalpoulaar	Rice	4	16
Djeol 1	Gorgol	14.2	72	0.16	1995	Male	Soninké/Haalpoulaar	Rice	1	17
Djeol 2	Gorgol	15.4	60	0.16	1979	Male	Soninké/Haalpoulaar	Rice	1	17
Gahara	Gorgol	0*	82	0.25	2003	Male	Black moor	Rice	1	18
Caldi Endam	Gorgol	19.8	23	0.26	2000	Female	Haalpoulaar	Rice	2	19
MEAN		29.0	61	0.36	1994				2	

*These schemes did not irrigate in 2008

and their location in the network. Additional unstructured interviews were held with farmers in order to corroborate the information supplied by the cooperative's board members and irrigation management personnel, and to gain an understanding of farmers' perceptions of the organisation, performance and problems of the irrigation scheme. After the introductory visit at the beginning of the irrigation campaign in each of the two years of the study, visits were repeated between one and three times, depending on need in each scheme, in order to complete and cross-check information, and to make further observations of the scheme during different phases of the irrigation campaign.

The pump keeper or, if illiterate, someone else who was familiar with the operation of the pump, maintained daily records of the starting and finishing pumping times and of the fuel consumption. Any incident related to the pump's operation and maintenance was also recorded, and all these records were checked weekly.

Pump discharge was measured at the head of the main irrigation canal by determining the canal cross-sectional profile at the point where flow velocity was measured with an acoustic velocimeter (SonTek FlowTracker Handheld ADV, SonTek, San Diego, California). Average flow velocity was obtained with the two-point method (Anonymous*,* 2007) applied to vertical profiles no more than 20 cm apart. Discharge was measured when the pump was operating at usual regime. If the scheme was supplied by more than one pump, then discharge measurements were repeated as many times as needed in order to obtain the discharge rates of each pump in their most frequent regime. Daily volumes of water supply were then computed from discharge rates and the duration of pumping.

In 2008, a specialist in pump electro-mechanics and maintenance carried out pump diagnostics in each irrigation scheme. The technician interviewed the pump keeper to gather information on the pump's technical characteristics, the adequacy of the pump motor, the pump's age, operation and maintenance procedures, quality of repairs, any other problems and risks of failure, and the pump keeper's qualifications.

With the aid of a GPS, the layout of the distribution system and the perimeter of both the irrigable and irrigated areas were recorded. This allowed to calculate the length of irrigation canals, irrigable and irrigated areas, and to sketch the distribution of plots.

In 2008, yields in each irrigation system were estimated based on a sample of 10 % to 20 % of the total cropped plots. The sample was distributed along different irrigation canals in order to be representative of the various conditions. For each selected plot, the total number of sacks of grain produced was counted, between 12 % and 15 % of the sacks were weighed, and the area of each plot was measured and recorded.

In the year 2007 it was not possible to gather complete data regarding water application, pump operation and crop yields. Thus, results in this paper are restricted to those derived from 2008 data.

4.3.3. Water balance

In order to compute external performance indicators related to water use, seasonal evapotranspiration, peak evapotranspiration rate and irrigation requirements under an optimum irrigation schedule (variables needed to compute performance indicators) were estimated based on a daily water balance model.

Daily rainfall data were obtained from the nearest pluviometric station (maximum distance, 30 km). Evapotranspiration was estimated using the FAO methodology, which is based on crop coefficients and reference evapotranspiration (Doorembos and Pruitt, 1977; Allen et al., 1998). Reference evapotranspiration (ET_o, mm) was calculated using the Penman-Monteith equation (Allen et al., 1998) and daily data of solar radiation, wind speed, air temperature, and relative humidity acquired from the agroclimatic station at Kaédi (for schemes located in Gorgol and Brakna) or Rosso (for the schemes in Trarza) (Figure 4.1).

Irrigation simulations were triggered in the water balance model whenever the root zone water deficit reached the allowable depletion for an optimum schedule, i.e, the root zone water deficit below which evapotranspiration is reduced in the case of crops other than rice, and 50 mm in the case of paddy rice. The net irrigation depth was defined as that necessary to refill the root zone: to field capacity, for non-paddy rice, or to saturation plus a free water depth of 100 mm, for paddy rice.

The number of simulations per scheme varied from 1 to 5, depending on the duration of the planting period and the number of rice varieties (one or two) cultivated in each scheme. A crop coefficient curve was drawn for each simulated field, based on the planting and harvesting dates of the respective crop and variety. Net irrigation requirements and evapotranspiration were then obtained for each scheme by averaging the values obtained from single simulations.

4.3.4. Irrigation performance indicators

Internal and external performance indicators that were found appropriate for the assessment of Mauritanian small and medium size community-managed irrigation schemes were selected from Molden and Gates (1990) and Bos et al. (2005).

Irrigation intensity assesses the actual agricultural use of the irrigable area (*II1*) or of the area habilitated for irrigation at the time of scheme construction (*II2*):

$$\mathrm{II1} = \frac{\text{total irrigated area}}{\text{total irrigable area}} \quad (1)$$

$$II2 = \frac{\textit{total irrigated area}}{\textit{total habilitated area}} \quad (2)$$

Water delivery capacity (*WDC*) quantifies the capacity of the main system to deliver the water that is required by the crops during the peak demand period.

$$WDC = \frac{\textit{pump or main canal capacity to deliver water}}{\textit{peak gross irrigation requirement}} \quad (3)$$

Delivery capacity at the head of the system may be limited by the pump capacity or the capacity of the main irrigation canal. To obtain gross irrigation requirements, net requirements (computed as explained in Section 0) were divided first by distribution efficiency, and then by application efficiency. The peak gross irrigation requirement was calculated for both irrigated and irrigable areas, to obtain *WDC1* and *WDC2*, respectively.

Relative irrigation supply (*RIS*) compares the amount of irrigation water required for maximum yield with the amount of water that is actually supplied:

$$RIS = \frac{\textit{supplied irrigation water}}{\textit{irrigation requirement for maximum yield}} \quad (4)$$

Irrigation requirements for maximum yield were calculated as the crop net irrigation requirements, or system gross irrigation requirements, denoted as *RIS1* and *RIS2*, respectively.

Beside land productivity (grain production per unit of irrigated area), water productivity and fuel productivity were also relevant indicators. Water productivity is defined as grain production per unit volume of irrigation water supplied:

$$WP = \frac{\textit{grain production}}{\textit{supplied irrigation water}} \quad (5)$$

Fuel productivity is similarly defined as grain production per unit of fuel consumed:

$$FP = \frac{grain\ production}{consumed\ \ fuel} \quad (6)$$

Consumed fuel may be expressed in units of volume or energy.

The quality of the water-delivery service is evaluated in terms of equity, reliability, flexibility, adequacy, and efficiency. Equity (*E*) refers to the fair distribution of available water; reliability (*R*) refers to the confidence in the ability to supply the demanded or arranged amount of water at the right time; flexibility (*F*) refers to the ability to decide the frequency, duration, and rate of supply; adequacy (*A*) refers to the capacity to meet the crop water requirements; efficiency refers to the capacity of the system to distribute and apply water with minimal water losses.

The indicators of the water-delivery service were quantified in terms of qualitative, comparative observations of specific pre-set criteria for each indicator. Thorough field observations were carried out simultaneously by three of the authors, accompanied by irrigation organisers and/or cooperative board representatives. After field visits, each observer scored each criterion on a scale from 0 to 4 and a discussion followed until a consensus was reached. Table 4.3 presents the criteria, scores, and weighing factors used to transform observations into indicators that were normalised to values in the interval between 0 and 1. In the case of efficiency, the interval was further restricted to the minimum and maximum values that previous experience suggested to be realistic. It should be noted, however, that the absolute value of these indicators for a given scheme should be treated with caution because they were based on qualitative observations, and were thus evaluated with a certain degree of subjectivity. Nevertheless, these indicators are valuable for comparing schemes that have been evaluated with the same criteria in the same way. Since distribution and application efficiencies have clear numerical definitions, and here we made qualitative estimations, we preferred using the terms indicator of distribution efficiency (*IDE*) and indicator of application efficiency (*IAE*) when referring to these two aspects of the water delivery service.

Table 4.3. Criteria, scores (S) and weighting factors (WF) for computing quantitative internal irrigation performance indicators based on qualitative observations.

Performance indicator and assessment criteria	WF or S
Indicator of distribution efficiency	
Spills	0.30
- Lot of spills (in main canal and > 75 % secondary canals)	0
- Frequent spills (in main canal and aprox. 50 % secondaries)	1
- Few spills (in less than 25 % of secondaries)	2
- Rare spills (localised and with little impact)	3
- No spills	4
Leaks	0.30
- Lot of leaks (in main canal and > 75 % secondary canals)	0
- Frequent leaks (in main canal and aprox. 50 % secondaries)	1
- Few leaks (in less than 25 % of secondaries)	2
- Rare leaks (localised and with little impact)	3
- No leaks	4
Filtrations according to measured length:area ratio	0.28
- If length:area > 0.015 m^{-1}	0
- If 0.015 m^{-1} > length:area > 0.012 m^{-1}	1
- If 0.012 m^{-1} > length:area > 0.009 m^{-1}	2
- If 0.009 m^{-1} > length:area > 0.006 m^{-1}	3
- If length:area < 0.006 m^{-1}	4
Filtrations according to observations	0.12
- Lot of filtrations (in main canal and > 75 % secondary canals)	0
- Frequent filtrations (in main canal and aprox. 50 % secondaries)	1
- Few filtrations (in less than 25 % of secondaries)	2
- Rare filtrations (localised and with little impact)	3
- No filtrations	4
Indicator of application efficiency	
Levelling	0.50
- Bad (>75 % of plots with marked elevation differences)	0
- Poor (about 50 % of plots with marked elevation differences)	1
- Fair (about 25 % of plots with marked elevation differences)	2
- Good (few plots with marked elevation differences)	3
- Excellent	4
Flattening	0.20
- Bad (>75 % of plots with marked elevation differences)	0
- Poor (about 50 % of plots with marked elevation differences)	1
- Fair (about 25 % of plots with marked elevation differences)	2
- Good (few plots with marked elevation differences)	3
- Excellent	4
Soil texture	0.30
- Light soils are predominant (>75 % of plots with light soils)	0
- Light soils are frequent (about 50 % of plots with light soils)	1
- Some light soil (about 25 % of plots with light soil)	2
- Few plots present light soil patches	3
- No light soils	4
Equity	

Organizational rules	0.30
- Inexistence of operation & maintenance (O&M) rules	0
- Vague and badly respected O&M rules	1
- O&M rules and authority relatively respected	2
- O&M rules and authority respected	3
- Clear O&M rules and authority well respected	4
Physical constraints for uniform distribution	0.30
- More than 50 % of plots have physical difficulties to receive water	0
	1
- More than 25 % of plots have physical difficulties to receive water	2
	3
- No plots with physical difficulties to receive water	4
Rotation among secondary canals for first irrigation	0.10
- Fixed rotation that creates inequity	0
- Fixed rotation but with some exceptions	1
- Rotation alternating each year	2
- Yearly alternating rotation plus additional measures favouring equity	3
- Flexible rotation oriented to favour equity	4
Rotation within secondary canals for first irrigation	0.10
- Fixed rotation that creates inequity	0
- Fixed rotation but with some exceptions	1
- Rotation alternating each year	2
- Yearly alternating rotation plus additional measures favouring equity	3
- Flexible rotation oriented to favour equity	4
Rotation order after first irrigation	0.20
- No preferences for plots unfavourably located do not have	0
	1
- Plots unfavourably located with some preferences	2
	3
- Plots unfavourably located with preferences to compensate disadvantages	4
Reliability	
Pumping station (scores taken from the pump specialized diagnostic)	0.35
- Old and with poor maintenance. Weekly failures	0
- Old with insufficient maintenance	1
- Old but with maintenance programme. Monthly failures	2
- New but maintenance may be improved. Infrequent failures	3
- New and with good maintenance program. No failures	4
Person(s) in charge of the pumping station	0.15
- Negligent	0
- Moderately negligent	1
- Moderately diligent	2
- Diligent	3
- Very diligent and well trained	4
Person(s) in charge of irrigation distribution	0.10
- Negligent	0
- Moderately negligent	1
- Moderately diligent	2
- Diligent	3
- Very diligent and well trained	4

Inundation risk	0.20
- Inundation every 3-4 years or part of the scheme inundated yearly	0
- Partially inundated every 3-4 years	1
- Some inundation risk and absence of protection levee	2
- Low inundation risk and absence of protection levee	3
- No inundation risk	4
Canals estate	0.20
- Poor state. Problems in canals interrupt irrigation often	0
- Poor state. Problems in canals interrupt irrigation from time to time	1
- Relatively fair state. Problems in canals interrupt irrigation rarely	2
- Good state. Problems in canals interrupt irrigation very rarely	3
- Excellent state	4
Flexibility	
Duration, flow rate and frequency of irrigation	1.00
- Fixed	0
- Flow rate or duration decided by farmer	1
- Flow rate and duration or frequency decided by farmer	2
- The three variables are decided by the farmer except for first irrigation	3
- Duration, flow rate and frequency of irrigation decided by farmer	4
Adequacy	
Irrigation schedule. Water deficit effect during the high water demand period	0.70
- > 75 % of plots suffer severe deficit	0
- 50-75 % of plots suffer severe deficit	1
- < 50 % of plots but a significant number suffer severe deficit	2
- Few of plots but a significant number suffer severe deficit	3
- There are no plots that suffer severe deficit	4
Drainage	0.30
- All plots have drainage problems	0
- More than half of the plots have drainage problems	1
- Less than half of the plots have drainage problems	2
- Few plots have drainage problems	3
- There are no plots that suffer drainage problems	4

4.4. Results

4.4.1. Internal assessment

Irrigation intensity

Although irrigation intensity referred to the area habilitated for irrigation (*II2*) did not exceed 0.66 in 50 % of the schemes (Figure 4.2), half of them had an irrigation intensity referred to irrigable area (*II1*) greater than 0.78. The high frequency values for low irrigation intensities and the separation between the *II1* and *II2* curves were signs of the schemes' degradation process, as discussed below. The case of Bélinabé, which was rehabilitated in 2005 (Mateos et al., 2010) and had an irrigation intensity *II2* = 0.18 (Table 4.4), epitomised this process.

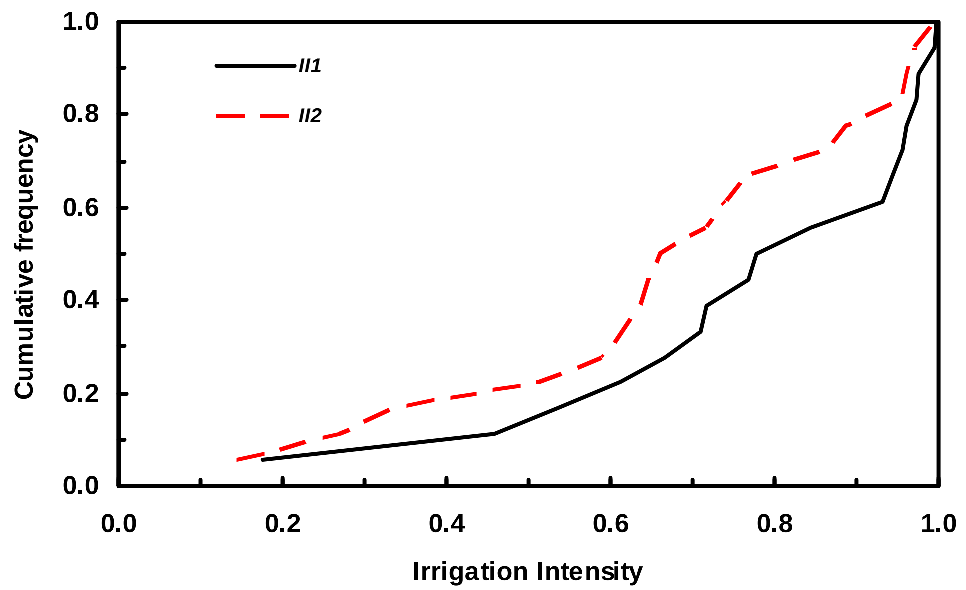

Figure 4.2. Cumulative frequency distributions of irrigation intensity referred to irrigable (*II1*) and habilitated (*II2*) areas.

<u>Water delivery capacity</u>

Limitations in the *WDC* of the pumping and conveyance systems were probably first the cause and then the effect of the low, and presumably diminishing, irrigation intensity. The water delivery capacity referred to the irrigated area (*WDC1*) was less than unity in a third of the irrigation schemes; and the capacity referred to the irrigable area (*WDC2*) was less than unity in almost two thirds of the schemes (Figure 4.3).

In the schemes where *WDC2* constrained water supply, the limitation was either at the pumping station (Bélinabé, Rindiaw-Silla and Tobeit) or in the conveyance system (Sinthiou, Caldi Endam, Djeol 2, Sare Souki, Aere M'Bara, Dagveg and Kéké). In Sinthiou and Sare Souki, the capacity of the conveyance system was limited by the small size of the head structure; strikingly enough, because these rudimental, small head basins may be easily enlarged.

It should be noted that delivery capacities were computed with respect to the usual duration of daily operation in each scheme and the prevailing conditions of the main irrigation canals when the discharge rates were determined. Increasing the daily operation time would increase *WDC* linearly; and eliminating weeds from the main canals could have an even greater effect on WDC (Mateos et al., 2010).

In some schemes where *WDC* was greater than unity, visual observations indicated that there could be water distribution limitations in the secondary system due to inadequate cross-sectional dimensions (e.g., Caldi Endam) or gradients (e.g., Sattara and Tandagha) of some canals.

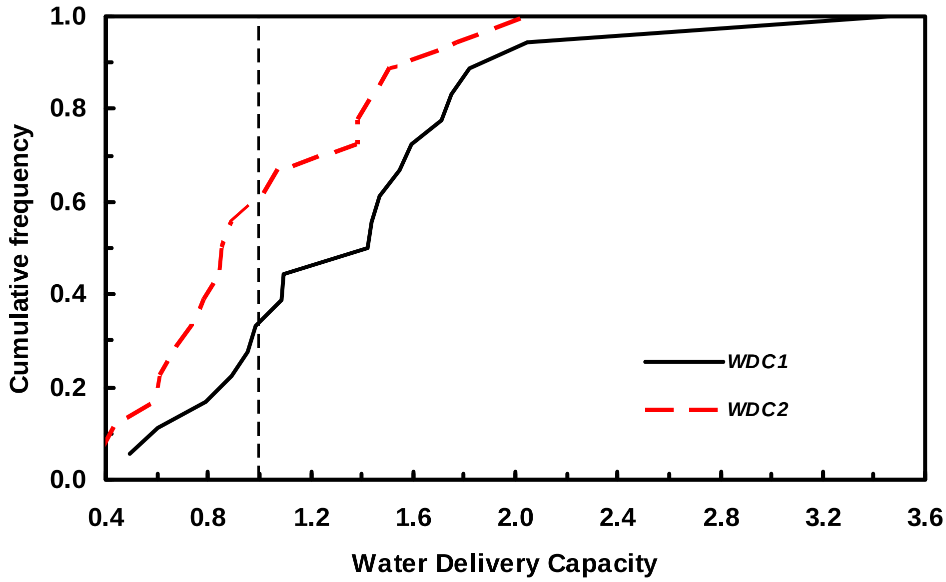

Figure 4.3. Cumulative frequency distributions of water delivery capacity referred to irrigated (*WDC1*) and irrigable (*WDC2*) areas.

<u>Water delivery service</u>

The distribution of the performance indicators presented in Figure 4.4 shows a wide range of variation. The average *indicator of distribution efficiency* (*IDE*) was 0.76 (Figure 4.4 and Table 4.4). The lowest *IDE* (0.64) was observed at Caldi Endam Table 4.4), where seepage and spill losses were evident due to the degraded condition of irrigation canals. Floods badly damaged the canals and protection dykes in 2003 and 2007. In other schemes, insufficient capacity of main and secondary canals (Figure 4.3) drove system operators to maintain water flow at the limit of canals' capacity. This often resulted in over-spills that reduced *IDE*.

Interestingly, rehabilitated schemes presented two types of water loss that were absent in non-rehabilitated schemes. The first type was leakage through breaches in the irrigation canals due to poor compaction of the banks. Secondly, in rehabilitation projects, canal bifurcations were usually upgraded by constructing concrete structures into which steel gates were installed. Often these gates did not fit properly in their sliding grooves and water leaked out. Overall, *IDE* might not be significantly reduced by these losses, but the results were striking in recently rehabilitated schemes like Bélinabé, Wabounde, and Garak 3, and to a lesser extent in Breun Goyar, which had an average *IDE* of 0.78, while the *IDE* was highest (0.82) at Dagveg, a non-rehabilitated scheme (Table 4.4).

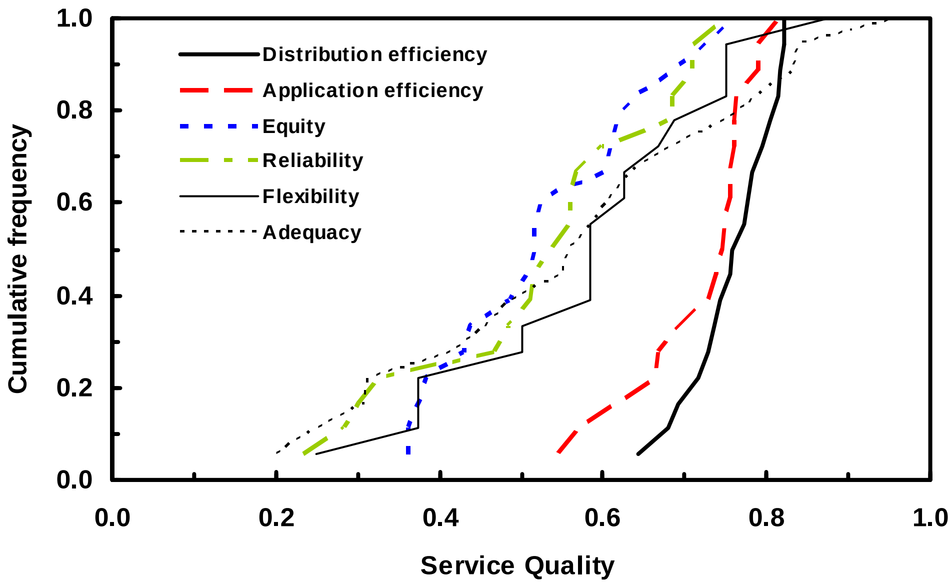

Figure 4.4. Cumulative frequency distributions of performance indicators related to the water delivery service: indicators of distribution and application efficiencies, equity, reliability, flexibility and adequacy.

The average *indicator of application efficiency* (*IAE*) was 0.72 (Figure 4.4 and Table 4.4), estimated from land levelling, flatness, and soil type (Table 4.3). Observant farmers overcame poor land levelling by dividing their plots into smaller sub-plots; and in schemes with lighter soils, crops other than rice were sometimes grown to avoid excessive percolation. Breun Goyar and Aere M'Bara have very heavy soils. In the former, plots were levelled during rehabilitation in 2004; in the latter, plots were small (0.2 ha) and divided into sub-plots. *IAE* was highest in these two schemes (Table 4.4) whereas in Djeol 2, where light soils are widespread across almost half the area, farmers persisted in growing rice, which resulted in *IAE* of only 0.55 (Table 4.4).

The highest levels of equity (E ≥ 0.69) were found in Rindiaw-Silla, Dagveg and Breun Goyar (Table 4.4).

Clear rules were set in these schemes concerning the farmer's irrigation turn, the maintenance of irrigation canals, and policy measures taken to enforce respect of the

Table 4.4. Performance in indicators in the studied irrigation schemes that irrigated in the 2008 wet season: *II1*: Irrigation intensity referred to irrigable area; *II2*: Irrigation intensity referred to the area habilitated at the time of scheme construction; *WDC1*: Water delivery capacity referred to irrigated area; *WDC1*: Water delivery capacity referred to irrigable area; *A*: Adequacy; *IDE*: Indicator of distribution efficiency; *IAE*: Indicator of application efficiency; *E*: Equity; *R*: Reliability; *F*: Flexibility; *D*: Irrigation depth; *RIS1*: Relative irrigation supply referred to crop net irrigation requirements; *RIS2*: Relative irrigation supply referred to system gross irrigation requirements; *LP*: Land productivity; *WP*: Water productivity; *FP*: Fuel productivity.

Scheme	*II1*	*II2*	*WDC1*	*WDC2*	*A*	*IDE*	*IAE*	*E*	*R*	*F*	*D* (mm)	*RIS1*	*RIS2*	*LP* (t/ha)	*WP* (kg/m^3)	*FP* (kg/kWh)
Breun Goyar	0.74	0.97	1.82	1.77	0.84	0.78	0.79	0.69	0.75	0.88	1732	2.02	1.25	5.68	0.33	3.34
Garak 2	0.77	0.84	1.71	1.44	0.59	0.69	0.75	0.44	0.48	0.50	1719	1.85	0.95	4.36	0.25	2.53
Garak 3	0.87	0.94	1.47	1.38	0.75	0.81	0.66	0.52	0.68	0.58	1130	1.25	0.67	3.24	0.29	2.79
Tandagha	0.96	0.96	1.44	1.38	0.49	0.74	0.69	0.36	0.57	0.38	850	1.18	0.60	3.89	0.46	4.18
Sattara	0.52	0.61	1.75	1.07	0.25	0.73	0.57	0.38	0.56	0.75	968	1.51	0.63	2.71	0.24	1.98
Kéké	0.59	0.67	0.99	0.66	0.63	0.82	0.73	0.49	0.51	0.75	736	1.44	0.86	4.62	0.41	3.21
Tobeit	1.00	1.00	0.79	0.78	0.46	0.80	0.67	0.52	0.71	0.58	891	1.08	0.57	2.72	0.31	2.26
Bakaho	0.64	0.98	1.55	1.51	0.56	0.77	0.76	0.64	0.56	0.58	1118	2.02	1.19	3.30	0.28	1.02
Dagveg	0.96	0.96	0.89	0.85	0.83	0.82	0.76	0.73	0.71	0.75	655	1.18	0.73	4.76	0.63	6.42
Wabounde	0.97	0.99	2.05	2.04	0.68	0.80	0.74	0.53	0.60	0.67	1512	1.80	1.06	3.83	0.25	1.91
Sare Souki	0.34	0.54	1.09	0.59	0.20	0.76	0.76	0.62	0.24	0.38	631	0.99	0.56	0.60	0.09	0.52
Aere M'Bara	0.27	0.46	1.59	0.73	0.79	0.82	0.82	0.60	0.30	0.69	1690	2.66	1.78	3.08	0.18	1.30
Sinthiou	0.89	0.93	0.95	0.89	0.31	0.72	0.76	0.43	0.52	0.38	516	0.88	0.48	0.63[*]	0.11[*]	0.77[*]
Rindiaw-Silla	0.72	0.72	0.60	0.43	0.96	0.78	0.79	0.76	0.69	0.63	701	0.82	0.50	3.66	0.49	2.23
Bélinabé	0.14	0.18	3.46	0.61	0.31	0.76	0.75	0.51	0.33	0.58	1389	1.90	1.08	1.77	0.11	0.82
Djeol 1	0.65	0.71	1.42	1.01	0.61	0.74	0.76	0.61	0.53	0.25	1257	1.77	0.99	3.25	0.26	1.64
Djeol 2	0.62	0.77	0.49	0.38	0.55	0.68	0.55	0.36	0.47	0.50	645	0.92	0.34	1.50	0.23	1.42
Caldi Endam	0.66	0.78	1.09	0.85	0.42	0.64	0.62	0.38	0.28	0.63	1369	2.13	0.84	4.45	0.33	2.70
MEAN	0.68	0.78	1.40	1.02	0.57	0.76	0.72	0.53	0.53	0.58	1084	1.52	0.84	3.38[**]	0.30[**]	2.37[**]

rules. Another crucial aspect of these schemes was the implementation of measures to deliver more water to those plots that, for physical reasons, were difficult to irrigate. This was achieved by irrigating more frequently, for longer durations, or with larger discharge rates by closing turnouts or secondary canals. These measures were usually conditioned by good performance observed through other indicators like delivery capacity, and distribution and application efficiencies. In other schemes, despite actions taken by irrigation managers to compensate for physical and infrastructural hindrances, adverse effects could not be entirely eliminated. This was exemplified by the case of Caldi Endam, where farmers located at the downstream end of secondary canals with slope decreasing along the canal reported that they had the right to ask for additional water. However, this additional water could not be easily delivered to the tail-ends of these canals with changes in slope and, thus, the problem persisted.

Caldi Endam, Djeol 2, Tandagha, and Sattara showed lowest equity ($E \leq 0.38$; Table 4.4), mainly because these schemes have significantly more structural and physical shortcomings (insufficient plot levelling, land depressions, irregular slopes of some secondary canals) than the best performing ones. Moreover, in some schemes (e.g., Tandagha) the irrigation organiser lacked the diligence or the authority to take measures that might balance structural inequities.

Reliability (Figure 4.4) varied from 0.24 (Sare Souki) to 0.75 (Breun Goyar). This wide range of variation can be explained by the multiple factors that determined it (Table 4.3). The condition of the pumping station, which was influenced by its age and maintenance, was clearly the most relevant factor in determining reliability. This criterion was assigned the highest weight (Table 4.3), and, at the same time, it was the one with the lowest average score. It follows that low values of R are largely attributable to this factor. Yet, another important factor determining reliability was the risk of floodings, which explains the second lowest value of R (0.28, in Caldi Endam, Table 4.4). Furthermore, in Gahara the perceived risk of flooding was so strong that the cooperative decided not to cultivate during the 2008 wet season.

Rehabilitation had an important effect on R. Out of the eight schemes that were most recently rehabilitated (Table 4.2), six were among the top seven with respect to R values ($R > 0.57$). However, it is interesting to note that a recently rehabilitated scheme (Bélinabé) had $R = 0.33$, whereas a scheme that was constructed in 1989 and has never since been rehabilitated (Dagveg) yielded the second highest value of R ($R = 0.71$)

(Table 4.4).

Given the rudimentary irrigation infrastructure and the relatively simple management requirements, farmers were generally free to decide the number of plot outlets and outlet discharge rates, which they could conveniently manage. The duration of irrigation was variable and depended on the criteria used by each farmer.

Breun Goyar was the system with the greatest *flexibility* (F = 0.88; Table 4.4). Irrigation turns were negotiated with the president of the water commission. This flexibility owed much to agreements between farmers, and to the possibility of irrigating at night. In Dagveg (F = 0.75) especially, but also in Kéké (F = 0.75), water was also said to be distributed on demand. Water users in Kéké even seemed to be allowed to operate secondary gates by themselves.

We found flexibility to be remarkably low ($F \leq 0.38$) in Sare Souki, Tandagha, Djeol 1 and Sinthiou (Table 4.4). In some systems, such as Sare Souki, under normal circumstances farmers would have a certain level of autonomy to plan when and how long they would like to irrigate. However, when infrastructural or technical shortcomings appeared, limits were set mainly on irrigation duration. In Sare Souki, flexibility was often restricted due to serious problems at the pumping station. In these circumstances, the strategy was to give little water to as many plots as possible letting equity prevailing over flexibility.

Despite repeated problems at the pumping station in Bélinabé, flexibility in this scheme was not the lowest recorded (F = 0.58) as irrigation intensity was very low (Table 4.4).

Greater flexibility was usually agreed to farmers that needed water for nursery stock, for sowing, or transplanting. Flexibility was also highly dependent on how much water was needed. When only a small amount of water was required to increase the water depth on a farmer's plot, water was assigned even if the irrigation turn was currently directed elsewhere in another secondary canal. However, if regular irrigation was required, the farmer would usually have to wait until water was passed to his or her secondary canal. This was observed in Kéké, Wabounde, and Sattara.

Kéké and Wabounde were schemes in which flexibility was implemented in different ways according to soil types. In Wabounde, for instance, farmers located at the 20-ha upstream sector had priority in irrigation because of the light texture of their soils, whereas at the larger, downstream sector, frequency seemed to be restricted.

In addition, in Caldi Endam, farmers were treated differently according to where their plots were located. Downstream farmers could ask for water more frequently as the irregular slope of canals affected their water supply. However, this agreed flexibility was then limited by physical constraints, with the result that tail-enders were not able to irrigate with the flexibility that they were supposed to have.

From these examples it emerged that flexibility was not a rigid characteristic, but varied along with factors such as soil type, location in the system, system maintenance and design, the authority of those who managed the irrigation, and irrigation intensity.

A distinction can be made between formal and informal flexibility. The former refers to flexibility deriving from formal water distribution rules and transparently-arranged delivery schedules; the latter refers to any unaccounted freedom to get water (water is diverted clandestinely or without permission of the irrigation organiser). If informal flexibility occurs as a consequence of weak irrigation control by the irrigation authorities, then equity is threatened and this may conversely lead to inflexibility (Bandaragoda, 1998). However, if informal flexibility is linked to an excess of capacity in the distribution system, this may bring fair benefits to farmers. The flexibility data in Figure 4.4 and Table 4.4 mainly reflect formal flexibility, since informal flexibility is more variable, prone to rapid change, unpredictable and difficult to estimate. However, the borderline between formal and informal flexibility, in the studied irrigation schemes, was often hazy.

Although the frequency distributions of *E*, *R* and *F* followed similar trends (Figure 4.4), this was not necessarily evidence of a strong correlation between these indicators (Table 4.5). *Adequacy,* however, integrates, to some extent, all water delivery service indicators. It is, in fact, the internal performance indicator that is closest to productivity. Average adequacy was estimated at 0.57 (Figure 4.4). It was lowest in Sare Souki (A = 0.20) and greatest in Rindiaw-Silla (A = 0.96). Adequacy was also greater than 0.80 in Breun Goyar and Dagveg (Table 4.4).

Stepwise forward multiple regression analysis showed that internal indicators other than A explained up to 56 % of the variability of A. E had the highest simple correlation with A (Table 4.6).

R contributed most to an increase in r^2, while the other internal indicators (*IDE*, *IAE*, *F*) did not contribute to a significant increase in r^2 (Table 4.6). [However, note that the correlation matrix (Table 4.5) indicates a relatively high correlation between *A* and *IDE* or *IAE*. Other multiple regression models also explained a significant part of the variance of *A,* although less than 56 %.]

Table 4.5. Matrix of correlation coefficients between pairs of internal irrigation performance indicators: indicator of distribution efficiency (*IDE*), indicator of application efficiency (*IAE*), equity, (*E*), reliability (*R*), flexibility (*F*) and adequacy (*A*).

	IDE	*IAE*	*E*	*R*	*F*	*A*
DE	1.00					
AE	0.52	1.00				
E	0.62	0.72	1.00			
R	0.42	0.05	0.33	1.00		
F	0.23	0.00	0.30	0.33	1.00	
A	0.51	0.40	0.61	0.55	0.38	1.00

Table 4.6. Summary of stepwise forward multiple regression analysis of adequacy vs.equity (*E*), reliability (*R*), flexibility (*F*) indicator of application efficiency (*IAE*) and indicator of distribution efficiency (*IDE*).

Performance indicator	No. of variables	r	r^2	F	p-level
E	1	0.607	0.369	9.351	0.008
R	2	0.715	0.511	4.341	0.055
F	3	0.739	0.546	1.107	0.311
IAE	4	0.746	0.557	0.305	0.590
IDE	5	0.746	0.557	0.008	0.931

4.4.2. External assessment

The contribution of rain to crop water consumption was relatively small (seasonal rainfall amounted to 238 mm and 315 mm in Rosso and Kaédi, respectively). Irrigation depth varied from 516 mm to 1732 mm (Figure 4.5). The former value corresponded to Sinthiou, the only scheme where sorghum was grown instead of rice; the latter corresponded to Breun Goyar, the scheme where, as discussed below, rice production was most intensive (Table 4.4).

RIS1 values indicated that in most schemes (about 80 %) an excess of water was applied in relation to the crop net irrigation requirements (*RIS1* > 1) (Figure 4.5). This excess was due mainly to low distribution and application efficiencies. In fact, *RIS2* values indicated that the percentage of schemes where fields appeared to be overirrigated (*RIS2* > 1) was only 30 %; whereas 70 % of the fields did not receive enough water (Figure 4.5). Although adequacy may be achieved through over-supply (Vandersypen et al., 2006), note that a *RIS* value greater than unity does not necessarily mean adequate irrigation. As mentioned above, adequacy values in many schemes were notably lower than unity. It may be stated, therefore, that irrigation water is frequently mis-used in the small irrigation schemes on the Mauritanian side of the Lower Senegal Valley.

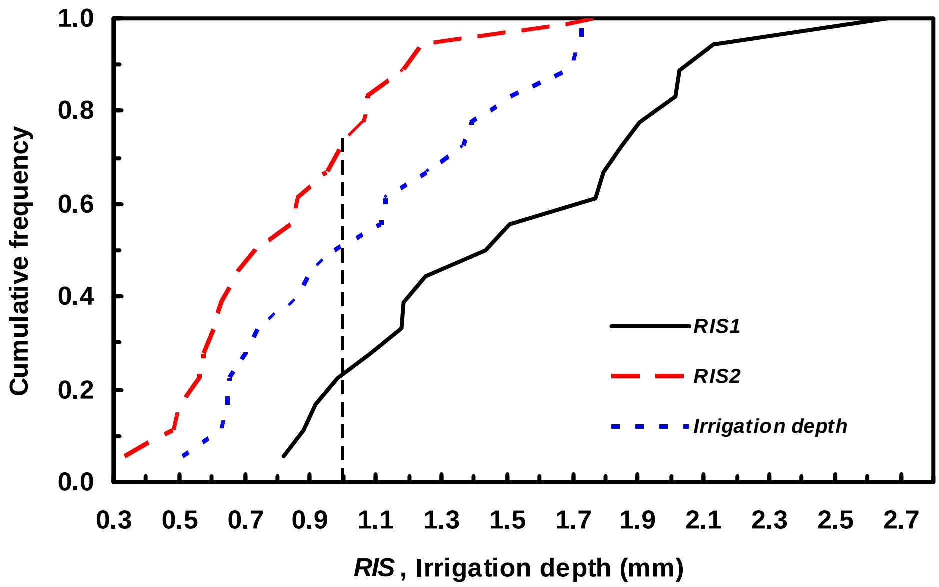

Figure 4.5. Cumulative frequency distributions of seasonal irrigation depth and relative irrigation supply computed considering crop net irrigation requirements only (*RIS1*) and computed at the system head (*RIS2*).

Rice yield averaged 3.38 t ha^{-1} and ranged from 0.60 t ha^{-1} to 5.68 t ha^{-1}, in Sare Souki and Breun Goyar, respectively (Figure 4.6 and Table 4.4). Sinthiou produced 0.63 t of sorghum per ha. Overall, although yield was very poor, it was within the range previously reported for the Senegal Valley by Wopereis et al. (1999), Haefele et al. (2001) and Poussin et al. (2003). However, it should be noted that the unit of analysis in those studies was the field, whereas in the present study the unit of analysis was the irrigation scheme. This explains why the maximum yield reported in the cited studies was between 8.2 t ha^{-1} and 9 t ha^{-1}, while in the present study it was only 5.68 t ha^{-1}. Yet, yields greater than 8 t ha^{-1} were measured in some of the plots sampled in Tobeit and Breun Goyar.

Land productivity was related to internal irrigation performance. Adequacy, the indicator that integrates other water delivery service performance indicators, explained 43 % (r = 0.66) of yield variability (Figure 4.7). Considering that the internal performance indicators were determined during the irrigation campaign, well before harvesting, it can be asserted that adequacy was a good predictor of yield.

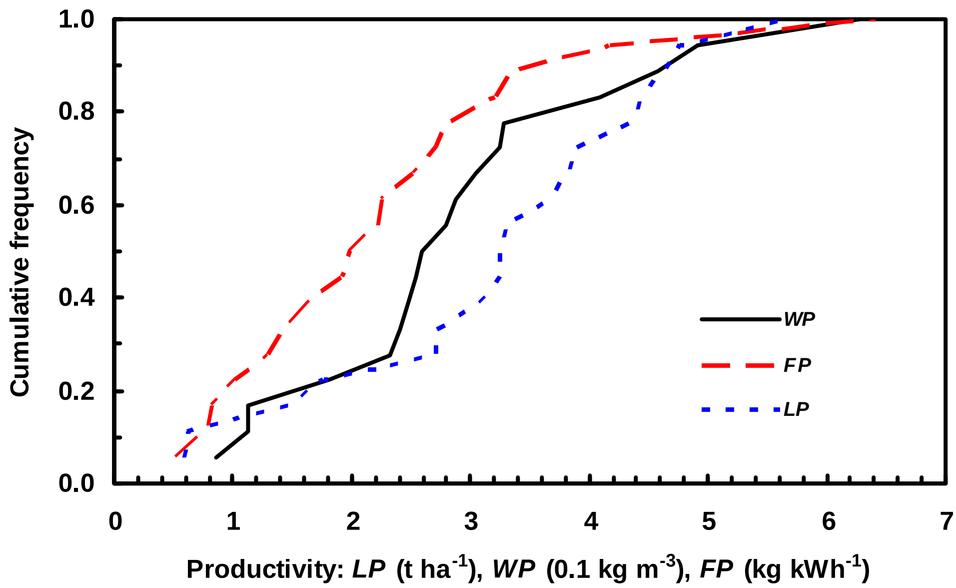

Figure 4.6. Cumulative frequency distributions of land (*LP*), water (*WP*) and fuel productivities (*FP*).

This finding was consistent with the results reported by Styles and Mariño (2002) and Okada et al. (2009), who related yield to an integrated water delivery indicator in 16 irrigation schemes. Although their indicator represented overall performance, not only adequacy as described in the present paper, it did refer to a range of very diverse irrigation schemes spread all over the world.

The interval of variation of water productivity was almost as wide as that of yield (Figure 4.6). The maximum water productivity was observed in Dagveg (0.63 kg m^{-3}), where it was seven times higher than the water productivity recorded in Sare Souki. However, water productivity is a very important aspect in this region as pumping costs are very high. The average fuel cost in the schemes in the present study was 33,700 ouguiya per ha (range: 15,000 to 70,000 ouguiya ha^{-1}) (340 ouguiya = 1 €). This cost represented, on average, 30 % of the campaign loan. The amount of fuel consumed varied from 60 l ha^{-1} to 280 l ha^{-1}. In terms of fuel productivity, this means that 80 % of the schemes did not achieve fuel productivity greater than 2.74 kg kWh^{-1} (caloric value of diesel: 10.96 kWh^{-1}) (Figure 4.6). Dagveg, where fuel productivity reached 6.39 kg kWh^{-1}, was an exception (Table 4.4).

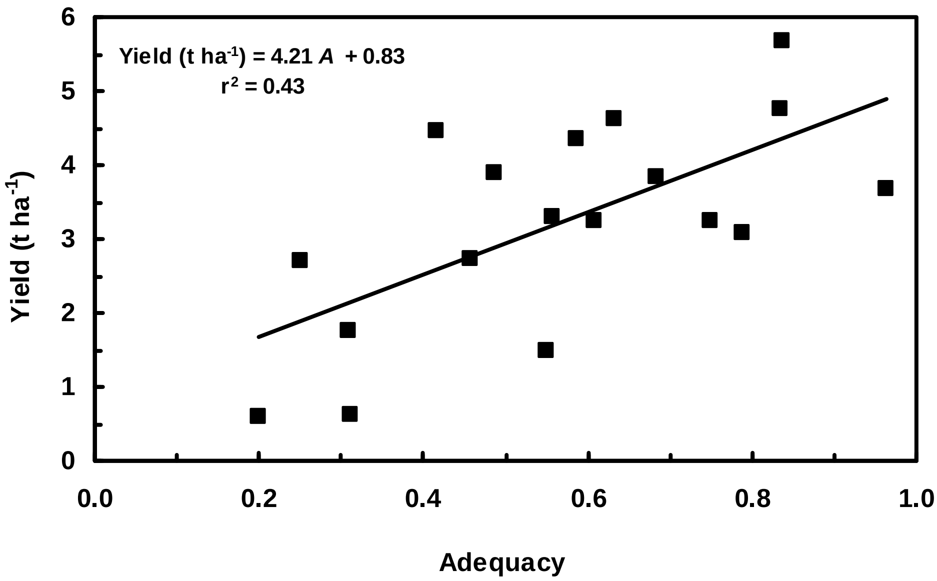

Figure 4.7. Schemes' average rice yield vs. adequacy (*A*).

4.5. Discussion

It was evident that all irrigation schemes were degraded to some degree. The degradation of irrigation schemes is a negative feedback process in which malfunctioning of one aspect triggers defective performance in another that, in turn, exacerbates the primary problem. When and why this process is initiated are key questions, answers to which will help improve the poor performance of Mauritanian irrigation schemes. Said this, performance gap turned out to be significant, and shows that there is room for improvement.

Table 4.7 compares the 8 schemes rehabilitated after 2000 with the rest of the schemes. For instance, referring to the water delivery service, mean *R*, *F* and *A* of recently rehabilitated schemes was higher than the respective means for non-rehabilitated schemes, however these differences were not statistically different ($P > 0.05$). *IDE*, *IAE* and *E* presented practically the same mean in both groups of schemes. Delivery capacity was improved by the rehabilitation projects; at the time of evaluation it was 27 % (*WDC2*) higher in the rehabilitated schemes than in the others (Table 4.7). However, when compared the two groups of schemes, this improvement was not statistically significant ($P > 0.05$) due to very low values of *WDC* in some of the recently rehabilitated schemes (Table 4.4).

Table 4.7. Selected irrigation performance indicators averaged for recently rehabilitated and non rehabilitated irrigation schemes.

Performance Indicator	Recently rehabilitated	Non rehabilitated
Date of construction or last rehabilitation	2004	1986
Irrigation intensity (*II1*)	0.82	0.75
Water delivery capacity (*WD2*)	1.16	0.91
Relative irrigation supply (*RIS2*)	0.82	0.85
Land productivity (t ha^{-1})	3.66	2.88
Irrigation depth (m^3 ha^{-1})	11968	9936
Water productivity (kg m^{-3})	0.32	0.27
Fuel productivity (kg kWh^{-1})	2.53	2.08
Indicator of distribution efficiency	0.76	0.75
Indicator of application efficiency	0.71	0.72
Equity	0.53	0.53
Reliability	0.58	0.49
Flexibility	0.61	0.55
Adequacy	0.61	0.53

Yield in recently rehabilitated schemes was on average 27 % greater than in non-rehabilitated ones (Table 4.7), which is a low percentage considering that the yield gap, i.e., the difference between actual and attainable yield, was still large (Wopereis et al., 1999; Haefele et al., 2001; Poussin et al., 2003). Moreover, the difference of mean yield in rehabilitated and non-rehabilitated schemes was not statistically significant ($P > 0.05$), indicating that, in some schemes (for instance, Bélinabé), the rehabilitation projects failed in their productivity goals.

The high frequencies of low irrigation intensities shown in the cumulative curves of both *II1* and *II2,* and the separation between them (Figure 4.2), was the indication in 2008 of the gradual abandonment of many irrigation schemes in Mauritania. It is difficult to determine the precise point of the degradation spiral at which each scheme currently stands. Some schemes seemed to have reached a state of complete abandonment during the period in which the present study was conducted, in particular, Dioude Dieri, Thiambène, and Gahara. These schemes were abandoned in the period between the 2007 and 2008 irrigation campaigns. In Dioude Dieri and Thiambène, the yield in 2007 was very low due to the precarious condition of the irrigation systems and particularly of the pumps. Consequently, the two cooperatives were unable to refund the campaign loan and they could no longer obtain further credit in order to repair the pumps or buy new ones. Eventually, during a general assembly, farmers decided not to engage in the 2008 campaign. The case of Gahara was different: in four of the last seven years, floods either severely damaged the levees that were supposed to protect the schemes or destroyed (partially or entirely) the crops. In 2008, the farmers decided not to take the risk again. Although it cannot be said that Bélinabé was abandoned, the rapid degradation, which immediately followed its rehabilitation –probably owing to faulty design (Mateos et al., 2010) – resulted in such low irrigation intensity in 2008 that the scheme was risking abandonment.

As opposed to these examples, other schemes showed comparatively good performance, even after a large number of years without any major intervention. Dagveg was exemplary in this respect.

Given the lack of machinery in the area, maintenance that has been deferred constitutes a major local constraint. Board representatives of all studied cooperatives stated that they relied on government or international aid to undertake this type of maintenance, which was done normally through rehabilitation projects. Preventive maintenance (e.g., reinforcing irrigation canal banks at points where breaches may occur) was non-existent in all studied schemes, and routine maintenance (weeding canals and pump maintenance) was irregular in most of them. Corrective maintenance, which we could often directly observe during our field visits, was therefore the prevalent type. This type of maintenance is often a consequence of sudden, unexpected events or progressive deterioration, which usually requires urgent action, and should be thus avoided wherever possible by implementing preventive and routine maintenance (Sagardoy et al., 1982).

The relatively good correlation between yield and adequacy (Figure 4.7) demonstrated that internal performance had a crucial effect on production. Poussin et al. (2006) also reported a revealing example in which an improvement in adequacy (achieved through planned cropping calendars and irrigation schedules) resulted in an 80 % increase in the gross margin of a small irrigation scheme 60 km from Rosso. Our perception was that farmers were aware of the adequacy-production link. They also recognised that water delivery services break down when maintenance is improper or inadequate. Why, then, were maintenance operations so often inadequate and, in most cases, clearly insufficient? The level of technical skill was sometimes a limitation (especially the level of training of the pump keeper), but because these irrigation systems are unsophisticated, their operators do not require high technical qualifications. In some cases it was evident that the design of the irrigation system, or its actual physical state, prevented its proper operation and discouraged maintenance endeavours. However, even when the state of the scheme was acceptable, few cooperatives were sufficiently cohesive to accomplish timely maintenance through the coordination of collective works. Cooperatives were unable to assign operational responsibilities to respected cooperative members or effective irrigation committees.

It is known that, in the Senegal Valley, delaying the beginning of the rice growing cycle reduces yield (Dingkuhn, 1995; Poussin et al., 2003). Moreover, scheme management becomes hasty if the delay is long. The early advent of rain may further delay the start of the growing season, distort irrigation schedules, and hinder crop production (Poussin et al., 2006). The interviewed cooperative representatives considered that the campaign had started on time in only four schemes (Bakaho, Tobeit, Dagveg, and Breun Goyar). The reasons for delayed planting alluded to in the rest of schemes included: technical reasons, for example, the unavailability of tractors for soil tillage (Rindiaw-Silla, Djeol 1 and Djeol 2); delays in processing campaign loan applications (Caldi Endam, Garak 2, Garak 3 and Sattara); the prolongation of the preceding dry season cropping campaign and other organizational hindrances (Bélinabé, Sare Souki, Aere M'Bara and Tandagha). Furthermore, representatives of cooperatives often declared that they tend to postpone the start of the campaign, until the first significant rainfalls occur, in order to save the cost of pre-irrigation. Our interviews could not prove that insufficient effort was the reason preventing timely start of the growing cycle. Rather, the conscious delay in starting cultivation entailed that farmers' main motivation was to minimize costs and labour rather than achieving high yields. This choice may be explained by a number of factors: the high cost of fuel; the competition for labour among the cropping systems that usually coexist in villages equipped with an irrigation scheme (Connor et al., 2008); the permanent or temporary emigration of labourers who then, via expatriate's associations, sustain villages from abroad (Diemer and Huibers, 1991; Lavigne Delville, 1991); and a trend towards part-time farming, which we detected during our investigation (although we did not quantify it) and has also been observed at the Officie du Niger irrigation scheme in Mali (Vandersypen et al., 2008).

The application of the rapid appraisal process in a participatory fashion was an effective way to systematically scrutinize technical constraints that were not apparent before the present assessment was conducted. It also revealed economic and socio-cultural elements that are so decisive in the performance of the irrigation schemes.

However, our assessment was unable to discern if farmers were sufficiently motivated to engage in intensive, highly productive irrigated agriculture that is economically self-sustainable. Future socio-cultural investigations should address this issue.

4.6. Conclusions

The irrigation schemes that were evaluated presented great variation in their state of deterioration. Their rudimentary construction made them particularly susceptible to degradation. System delivery capacity and water delivery service were generally insufficient to satisfy irrigation requirements. Lack of maintenance exacerbated this insufficiency. The sections of the irrigation system that were most difficult to irrigate were progressively abandoned, thus overall irrigation intensity was low. This process was further affected by the difficulties of the Cooperative Boards to obtain campaign loans, coordinate the timely initiation of the campaign, organise maintenance work, and schedule and control water distribution.

Overall, productivity was low. It seems that farmers opted for low input cropping. Low yields diminished the capacity and motivation for proper system maintenance and upgrading. Only if external funds were offered, would deferred maintenance or rehabilitation be undertaken.

On average, rehabilitated schemes performed slightly better than non-rehabilitated schemes; however, the variations among schemes were so large that the differences between performance indicators in rehabilitated and non-rehabilitated schemes were not statistically significant.

Nevertheless, relatively good performing schemes and the existing performance gap between schemes under comparable conditions are signs of potential for improvement. Therefore, policies and interventions should take into appropriate consideration their potential role in agricultural development, food security, and poverty alleviation.

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Chapter 5

Patterns of variability in large-scale irrigation schemes in Mauritania

5. Patterns of variability in large-scale irrigation schemes in Mauritania[1]

Abstract

Large-scale irrigation schemes have not yielded the expected outcomes in Sub-Saharan Africa. In Mauritania, average land productivity of rice schemes lies between 3 and 3.5 t ha^{-1} and irrigated land has progressively being abandoned. At the same time, there is new international attention towards interventions in large-scale irrigation in the Sahel. Spatial and temporal variability of production are main causes of low productivity of large-scale irrigation schemes in Mauritania and threats to their sustainability. The present paper focuses on the performance of three representative large-scale schemes located along the River Senegal by analysing intra-scheme variability with respect to yield and irrigation intensity using field observations and satellite images. A sample of tertiary canals was selected in each irrigation scheme for weekly surveys of irrigation processes and maintenance. Yield measurement, irrigation (II) and harvest intensity (HI), indicators of irrigation adequacy (IIA) and drainage adequacy (IDA) constituted the basis of this analysis. Semi-structured interviews with the different actors at the various management levels (farmers; cooperatives; union of cooperatives; state irrigation agency; and the private service provider managing the water delivery in one of the schemes) were held in order to gain information on irrigation and drainage infrastructure, organisation and management of the schemes, financial aspects and irrigated surface. Within each irrigation scheme, a great variability was detected with respect to irrigation intensity and yield. Irrigation intensity could vary as much as from 0 to 1 whilst yield could range from 0.4 to 7 t ha^{-1} in a single scheme.

The analysis of water distribution patterns at scheme level indicated that variability in irrigation supplies and drainage were main sources of variability of yields and irrigation intensity. Physical, technical, and organisational factors underlie non-uniform water distribution patterns. The understanding of the origins of patterns of variability is a first step towards a more realistic assessment of schemes' sustainability and contribution to food security.

Keywords: Yield variability; Irrigation intensity; Water distribution patterns; Drainage

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5.1. Introduction

Irrigation has been a fundamental element for poverty alleviation strategies in Africa and Asia (Rijsberman, 2003; Hussain and Hanjra, 2004). Examples from Ethiopia and sub-Saharan Africa have shown that irrigation has greater impacts when accompanied by measures addressing education, rural markets (Hanjra et al. 2009a, b) and rural infrastructure (Calderon and Chong, 2004) in an integrated fashion. Irrigation creates direct benefits by increasing productivity and cropping intensities. Indirect benefits are related to the creation of in-farm and off-farm employment, stabilisation of wages (Hussain 2007a), and the often neglected multiple uses of irrigation water (Hasnip et al. 2001). Yet, amid indisputable benefits, irrigation has not fully succeeded in reducing poverty (Hussain 2007b). This is particularly so in sub-Saharan Africa, where the development of large-scale irrigation, as compared to Asia, has been limited (Adams, 1991; Inoncencio et al., 2007; IWMI, 2007). Additionally, despite significant investments in the 1960s and 1970s, followed, since the late 1980s, by attempts in improving irrigation management, large-scale irrigation schemes have largely missed forecasted performance (Plusquellec and Burt, 2000). While water and land resources in sub-Saharan Africa are still largely unexploited (Ararso et al., 2008), the development and success of irrigation schemes are challenged by poor design, insufficient institutional and financial capacity, lack of technical skills and appropriation of irrigation equipment by water users (Inocencio et al., 2007). In the 1990s, low performance of large-scale irrigation had bent away donors' and governments' attention from large irrigation schemes. At that time, development policies advocated for small-scale irrigation as the right scale and approach to achieve economic growth and rural development through social transformation and access to subsidised technologies (Turner, 1994; Vincent, 1994).

After budget for irrigation had been drastically retrenched since the late 1980s, the food crisis of 2008 and the realisation by donors that they did not have an articulated irrigation strategy have directed renewed attention towards large-scale irrigation schemes (World Bank, 2008) and rice cultivation (Nakano et al., 2011) in sub-Saharan Africa. Hussain (2007a), after revising case studies from Asia centred on evaluating the impact of small-scale schemes on livelihood enhancement, concluded that no definite judgement could be traced on whether small-scale irrigation served better than large schemes the purpose of alleviating poverty.

Whilst small-scale schemes in Mauritania have already been subject of study by the authors (see Chapter 4), in the light of this new tendency towards large-scale irrigation, and before engaging in costly irrigation interventions, it is of paramount importance to look better into the outputs, internal functioning, and potential of large schemes. The present paper wants expressly to look into the causes and processes which lead to the often cited degradation-rehabilitation cycle (Plusquellec and Burt, 2000), the abandonment of irrigated land and the low productivity of large-scale irrigation in Mauritania.

Mauritania, with more than 80 % of desert, is a net importer of food. Apart from some cultivation in the oases, agriculture is only possible in a thin strip of land along the Senegal River Valley. Since irrigation thrived with the construction of the dams of Manantali (Mali) and Diama, river upstream and at its estuary, respectively, rice cultivation has always received special attention.

Past studies on large-scale irrigation schemes worldwide have been concerned with overall internal and external performance. Yet, few efforts have been directed on mapping the variability that may exist within an irrigation scheme with respect to specific outputs and the triggering factors behind this variability. Water distribution uniformity and equity already proved to be tightly related to land productivity (Steiner and Walter, 1992; Clemmens, 2006; Clemmens and Molden, 2007). Large-scale schemes, compared to small schemes, have more levels of hydraulic infrastructure and management. As multiple actors and structures have to interact and cooperate, these systems are also more sensitive to disturbances in the water distribution process (Clemmens, 2006) and production activities. As opposed to irrigation, drainage, and its effects on schemes performance, has so far received little attention (Smedema and Ochs, 1998), despite its primary role in guaranteeing sustainable use of irrigated land avoiding water-logging and salinisation (Smedema et al., 2000).

The objective of this paper is therefore to diagnose the performance of large-scale irrigation in Mauritania by analysing the patterns of variability of irrigation, drainage, and productivity.

5.2. Description of selected irrigation schemes

There are eight large-scale public irrigation schemes in Mauritania, covering an area of 8461 ha, which counts for about 20 % of the total area developed for irrigation of about 45,000 ha (FAO, 2005). They are distributed in the three regions of Trarza, Brakna, and Gorgol along the Senegal River. The selection of the study sample followed visits to all eight irrigation schemes during which general information was collected. Their surfaces range from 260 to 2000 ha, their average surface being 1000 ha. Rice is the main crop in all schemes with two schemes (Casier Pilote de Boghé, and Maghama III) cultivating also sorghum and some vegetables in more elevated areas not suited for rice. One of the 8 schemes, Maghama III, located in Gorgol, was discarded beforehand, being it an upgraded flood recession scheme and thus subjected to a different water management regime. Because the schemes situated near big cities have impact on a larger population, vicinity to these cities prevailed in the selection criteria. Therefore, the choice fell on the schemes M'Pourie (near Rosso), Casier Pilote de Boghé (CPB, next to Boghé), and Périmètre Pilote du Gorgol II (PPGII, at the outskirts of Kaedi), so that the three regions, Trarza, Brakna, and Gorgol, were represented. **¡Error! No se encuentra el origen de la referencia.** shows the location of the selected schemes.

5.2.1. Layout and infrastructure

The three studied schemes were constructed at different moments, M'Pourie in 1972, CPB in 1983 and PPGII in 1997. These large-scale schemes (area between 505 ha and 1405 ha) have several levels of irrigation infrastructure. A pumping station pumps water into a vast network of main, secondary, and tertiary canals. Hydraulic structures present variable level of technicality and automatism. A drainage network and drainage pumps complete the schemes' infrastructure. Table 5.1 summarises the main technical and physical characteristics of the studied schemes.

Whereas M'Pourie and CPB are located next to the river Senegal, PPGII is fed by the Gorgol, an affluent of the Senegal. PPGII can divert water also by gravity when the river water level rises above 10 m asl, and it is equipped with a storage basin with the double function of a buffer against water shortages and flooding.

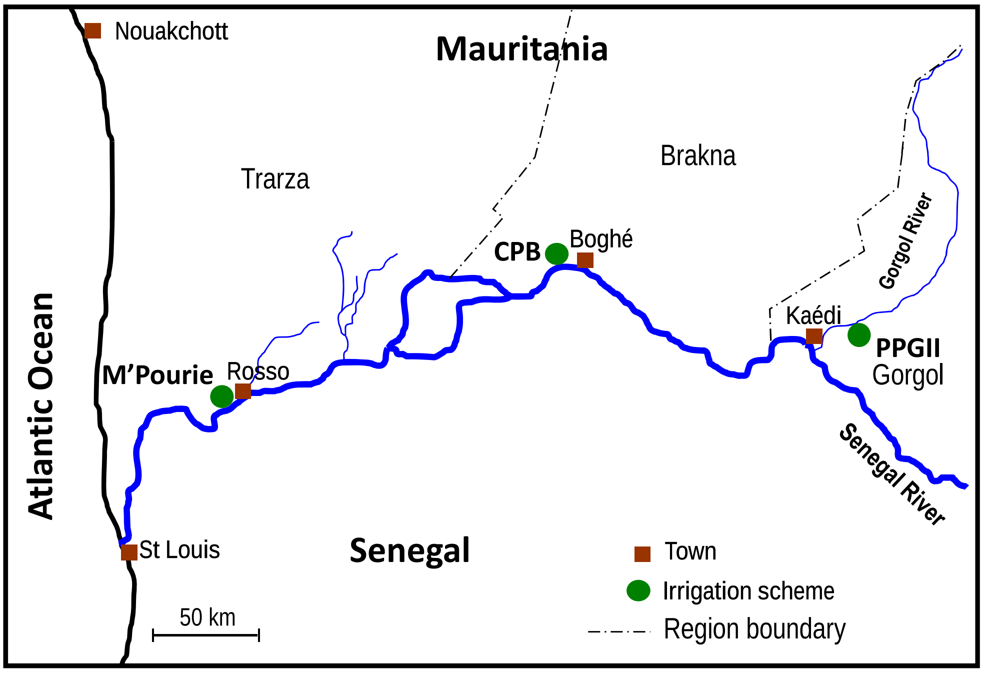

Figure 5.1. Location along the valley of the Senegal River of the large-scale irrigation schemes studied in the wet season 2009 abd 2010.

M'Pourie is divided into 11 irrigation sectors. Each secondary canal irrigates one or two facing sectors through 10−12 tertiary canals. CPB is divided into sectors A, B, and C plus a fourth sector located at the perimeter of the scheme where, due to its lighter soil and higher elevation, crops other than rice are grown. The surface of PPGII is subdivided into 30 sectors, 21 with an area of 36 ha, 4 of 48 ha, and 2 of 72 ha. Each sector belongs to one cooperative. Each unit of 36 ha is irrigated by three equidistant tertiary canals serving on both sides 6 ha.

5.2.2. Management, organisation and maintenance

At each level of infrastructure corresponds a level of management. There are farmers at plot level and several cooperatives at tertiary level. The management of the main and secondary system levels is typically shared between the state irrigation agency and a union of cooperatives of farmers; or, as in the case of M'Pourie, the water delivery has been subcontracted to a private service provider. In M'Pourie, the private service provider also cultivated parts of the scheme. Table 5.2 summarises the schemes' main institutional and organisational characteristics.

In CPB and PPGII, maintenance falls almost entirely under the responsibility of the union of cooperatives, who have to assess and organise works at main and secondary system levels. Farmers contribute in the form both of fixed fees and with their work. Lower system canals are maintained by farmers irrigating from them.

Chiefs of canals are responsible for organising water distribution chasing to harmonise water levels in the main canals with farmers' needs in the different parts of the irrigation system. There is communication between farmers, chief of canals, and technicians at the pumping station for the transmission of water demands and water levels. In case of disputes or water claims that overpass chief of canals or single farmers' resolution capacity, farmers may appeal to the president of the cooperative or to the board of the union of cooperatives.

Table 5.3 presents the main aspects related to operation and maintenance.

5.3. Materials and methods

5.3.1. Data collection: rapid appraisal process

The rapid appraisal process (RAP) is a systematic method for gathering and analysing information on irrigation schemes, both in the field and in the office. It permits qualified staff to assess the structure and processes of an irrigation scheme in an organised way and within a short period of time (Burt and Styles, 1999; Burt 2002; see Chapter 4). Collected information encloses external inputs (e.g., water supplies, cultivated surfaces, meteorological data) and outputs (e.g., yield), and the evaluation of hydraulic structures and processes of water distribution. Based on this data, internal irrigation performance indicators (water delivery service) and external performance indicators (those that relate outputs to inputs) are determined. The process further investigates socio-economic, organisational, and institutional features of the irrigation scheme.

First visits to the irrigation schemes at the beginning of the cropping season had the objective to meet higher management levels and to gain a first picture of the physical, technical, organisational, and socio-economic aspects. Based on semi-structured interviews, information was gathered on the history of the irrigation scheme and its main problems related to irrigation and drainage. Details concerning management included: the organisational structure, roles and activities; number of cooperatives and

Table 5.1. Main technical and physical characteristics of the studied large-scale irrigation schemes.

Scheme	M'Pourie	CPB	PPGII
Region	Trarza	Brakna	Gorgol
Irrigable area (ha)	1405	505	1117
Main crop	Rice	Rice and mixed crops	Rice
Plot size (ha)	Variable 0.3−1.0	0.5 rice; 0.23 other crops	0.5 and 1.0
Pumping capacity (m^3 s^{-1})	5.5	3.0	2.5
Number of pumps	7	6	6
Energy source	Gas oil	Electricity	Electricity
Main canal lining	Concrete	Earth	Earth
Lower canals lining	Earth	Earth	Earth
Canal operation	Semi-automated (float-operated gates; stepwise regulators)	Manual (concrete structures with metal gates; overflow structures)	Automated (float-operated gates)
Tertiary canal intake	Stepwise regulators	Proportional division boxes	Venturi modules

Table 5.2. Main institutional and organisational characteristics of the studied large-scale irrigation schemes.

Scheme	M'Pourie	CPB	PPGII
Type of management	Private–public	Public, transfer in process	Public, transfer in process
Actors	Private service provider, union of coops., cooperatives, private farmers	State irrigation agency, union of coops., cooperatives, farmers	State irrigation agency, union of coops., cooperatives, farmers
Land users	Private service provider (50 % area), cooperatives (39 %), private farmers (11 %)	Cooperatives	Cooperatives
Number of active land users	28 (of 40) cooperatives + 35 private farmers + private service provider	12 cooperatives	29 (of 30) cooperatives
Land tenure	Right to use land	Right to use land	Some farmers have property rights, most have right to use land
Fixed fees	30,000 UM[a] ha^{-1} for water service	16,700 UM[a] ha^{-1}, reduced to 9000 in 2010	16,700 UM[a] ha^{-1}, reduced to 9000 in 2010
Credit	Farmers regained access to credit	Cooperatives regained access to credit	Cooperatives regained access to credit
Production management	Individual	Cooperative	Cooperative
Commercialisation	Individual	GIE[b]	GIE[b]

[a]UM: Mauritanian monetary unit: 1€ = 350 UM.
[b]GIE (Groupement Interets Economiques): federative organisations for the commercialisation of rice.

Table 5.3. Main operation and maintenance characteristics of the studied large-scale irrigation schemes.

Scheme	M'Pourie	CPB	PPGII
Operation of main system	Manager, 5 chiefs of secondary canals, 2 technicians at the pumping station	2 chiefs of canals, 1 person responsible for the pumping station	2 technicians responsible for pumping station and canal operation; guardians for hydraulic structures
Type of water control	Upstream control integrated with downstream control	Upstream control integrated with downstream control	Downstream control
Water distribution method	During peak demand, regulation of flow among secondary canals; no rotation among tertiary canals; rotations among plots	During peak demand, rotation among sectors; no rotations among tertiary canals; rotations among plots	During peak demand, regulation of flows among secondary canals; no rotation among tertiary canals; rotations among plots
Operation at tertiary level	By farmer or a delegate farmer	By farmer or a delegate farmer	By farmer or a delegate farmer
Maintenance of main system	Private service provider	Union of coops.; farmers contribute with fixed fees and labour	Union of coops.; farmers contribute with fixed fees and labour
Maintenance at tertiary level	In theory cooperatives organise works; in practice single farmers discretion	In theory, cooperatives organise works; in practice single farmers discretion	In theory, cooperatives organise works; in practice single farmers discretion

members; plot size; cultivated surfaces; cropping patterns; water distribution rules and operation; maintenance; financial aspects (e.g., credit facilities); and commercialisation. Field visits to appraise the layout of the system, hydraulic structures and equipment, water distribution, and drainage, completed this first assessment. Following visits (four times per scheme during the cropping period) permitted to refine and cross-check this initial information by means of observations, interviews with farmers, presidents of cooperatives, and irrigation staff.

Additionally, surveys and observations were conducted weekly by local project staff to evaluate organisation, irrigation processes, and maintenance activities at tertiary system level. For this purpose, a sample of tertiary canals was selected for each irrigation scheme. This sample represented the various conditions with respect to physical characteristics (e.g., topographical elevation, soil type) and location in the irrigation scheme. In M'Pourie, two to three tertiary canals per sector were selected in sectors 4−11. Sectors cultivated by the private service provider (1−3) were not included in the tertiary level analysis but appear in the evaluation of external indicators (e.g., land productivity, irrigation intensities). In CPB, a sample of 12 tertiary canals covered the three sectors A, B, and C. In PPGII, 6 cooperatives were selected, five cultivating 36 ha irrigated by 3 tertiary canals, and one cooperative cultivating 48 ha irrigated by four tertiaries; thus a total number of 19 tertiary canals was studied. The 6 cooperatives represented the different topographical conditions of PPGII: two (sectors 1 and 5) were located in the higher elevated zone, two (sectors 17 and 18) in the intermediate zone, and two (sectors 27 and 28) in the lower areas. The samples in the three schemes covered approximately 10 % of the total cropped surface.

Yield was measured in every plot of the selected tertiary canals. At harvest, farmers used sacs of similar size to transport the rice grain from the plots to their houses. A minimum of 8 sacs per plot were weighed, the number of sacs per plot was counted, and the surface of the sampled plots was measured.

5.3.2. Internal indicators and mapping

Several of the indicators used in this study stemmed from Molden and Gates (1990) and Bos et al. (2005). Irrigation intensity (II) is defined as the fraction of irrigated over the area initially equipped for irrigation. Harvest intensity (HI) represents the ratio between harvested and irrigated area. II and HI were calculated at scheme level and at sector (M'Pourie) or cooperative (CPB and PPGII) level, according to the data available.

Indicators of irrigation (IIA) and drainage (IDA) adequacy were qualitative approximations of how well the plots were irrigated or drained. IIA and IDA were estimated for each plot along the selected tertiary canals through comparative evaluations made during regular field visit by project's observers and one of the authors. Scores on a scale from 0−3 were assigned according to specific criteria previously developed for the study of small irrigation schemes in Mauritania (**¡Error! No se encuentra el origen de la referencia.**) (see Chapter 4). The scores were then normalised to a 0−1 scale. Evaluations were made between September and November, coinciding with the development and middle stage of rice. For most plots two such evaluations were carried out and averaged for obtaining seasonal IIA and IDA values. Then, an IIA and IDA value was obtained for each tertiary canal as the average of single plot values. In addition to plot level evaluations in the sample of tertiary canals, overall irrigation and drainage conditions were assessed during field surveys directed to their understanding at the entire scheme level. During these visits, direct observations were combined with interviews to farmers, irrigation managers, state irrigation agency staff, and members of the board of the union of cooperatives. Then, the two-level assessment (sample level and overall scheme level) was integrated into maps of problematic areas with respect to irrigation and drainage conditions. The base layers of these maps were pre-existing maps of the schemes (with the irrigation, drainage, and road networks, and the sector boundaries), Google Earth images and soil and topographic maps (PNUD-FAO, 1977).

Table 5.4. Assessment criteria for the indicator of irrigation adequacy (IIA) and the indicator of drainage adequacy (IDA).

Internal performance indicators / criterion	*Score*
Indicator of irrigation adequacy (IIA)	
Severe deficit on most of the plot	0
At least half of the plot has insufficient water	1
Acceptable water level on most of the plot	2
Plot has optimum water level	3
Indicator of drainage adequacy (IDA)	
Most of the plot has severe drainage problems	0
Drainage problems on at least half of the plot	1
Plot has some excess water but without implications on crop	2
Plot is well drained	3

Spatial analysis of drainage conditions was further supported using Landsat 5 and 7 satellite images taken in October−November (25th October for M'Pourie, 3rd November for CPB, and 3rd October for PPGII), when the rainy season was over, the crops at a developing stage, and the areas with drainage problems stood out more neatly. Reflectance in the infrared band distinguishes water from vegetation or soil clearly (Richards and Jia, 2006, page 5), providing a trace of water-logging. The spatial resolution of Landsat 5 and 7 in the infrared band, 30 m, was appropriate for the scale of variation observed for drainage problems.

Additionally, a set of Landsat 5 and Landsat 7 images (Table 5.5) was used in M'Pourie to calculate, for each sampled tertiary canal, normalised difference vegetation index (NDVI) time series in 2009 and 2010. The NDVI is defined as the difference between the near-infrared and red reflectance divided by their sum (Rouse et al., 1974). The NDVI time series were used as input in a crop yield model with the hope of detecting yield variability patterns so to corroborate and expand data gathered in the field. The crop model calculates daily biomass production from photosynthetically active radiation (PAR, obtained from ground estimations of solar radiation), the fraction of PAR intercepted by the crop, and a radiation use efficiency (Monteith, 1972). The intercepted PAR fraction is obtained through a linear relationship with NDVI (Hatfield et al., 1984). Daily NDVI values are estimated by linear interpolation of NDVI measured on days of satellite overpass. Final biomass is converted into yield by multiplying it by a constant harvest index of 0.33. This value was also used by Zwart and Leclert (2010) in their remote sensing-based performance assessment of irrigated rice in Mali. This crop yield model was applied across the Indus basin by Bastiaanssen and Ali (2003) and by Zwart and Leclert (2010) in Mali including three corrections to the radiation use efficiency, two to account for temperature effects, and a third one to account for water deficit effects. We considered these corrections unnecessary in our application of the model. Based on our observations in the irrigation scheme where the analysis was conducted, waterlogging is the main issue while water deficit effects are secondary (this is discussed later in the paper). On the other hand, temperature function T1 adopted in Bastiaanssen and Ali (2003) is constant for a given crop and ambient, whereas function T2, which varies monthly, in the Lower Senegal valley gives practically constant values over the three months of rice growth. The radiation use efficiency that we used, 1.6 g MJ^{-1}, was the value that made simulated and measured average yields equal. Therefore, functions T1 and T2 were already accounted for in the tuned radiation use efficiency. The value used was within the range reported by Bastiaanssen and Ali (2003) for rice.

Landsat images were accessed on the web (http://glovis.usgs.gov/) through the GLOVIS portal of the United States Geological Survey.

Table 5.5. Date of the satellite images used in M'Pourie for the estimation of yield.

Date	*Satellite*	*Date*	*Satellite*
4 September 2009	Landsat 5	15 September 2010	Landsat 5
6 October 2009	Landsat 5	25 October 2010	Landsat 7
22 October 2009	Landsat 5	26 November 2010	Landsat 7
7 November 2009	Landsat 5		
15 November 2009	Landsat 7		
23 November 2009	Landsat 7		
9 December 2009	Landsat 5		

5.4. Results

In 2009, the study included the sole scheme of M'Pourie as in the schemes of CPB and PPGII no cultivation took place during the wet season; the former for lost access to credit facilities as cooperatives were indebted, the latter because of rehabilitation works. Thus, results are based on the year 2010. Data of 2009 for M'Pourie is restricted to irrigation intensity, harvest intensity, and land productivity and shall substantiate 2010 findings.

5.4.1. Physical and technical constraints

Drainage and irrigation problems were observed in the three irrigation schemes. Yet, their intensity, nature (drainage/irrigation), and cause took heterogeneous patterns of spatial distribution within each irrigation scheme. Figure 5.2 and Figure 5.4 show the distribution of problematic (moderate, severe) zones with respect to irrigation and drainage.

Irrigation problems

Main causes of irrigation problems were: differences in elevation across the scheme and underperforming irrigation infrastructure. In PPGII, irrigation problems originated mainly out of topographical conditions. The scheme can be divided in a higher elevated zone upstream (9.5−10 m asl) in the western side, next to the pumping station (sectors 1 to 5 and part of 25); an intermediate zone (9−9.5 m asl) located in the central part of the scheme (sectors 6, 7, 8−13, 15, 17−19, and 24); and a lower zone (8−9 m asl) in the eastern side (sectors 14, 16, 20−23, and 26−30) (Figure 5.2). In some of the higher areas, water supplies were highly inadequate and irrigation problems were evaluated as severe (Figure 5.2). The minimum tertiary canal IIA was 0.40 (Table 5.6), recorded in sector 4, the sector nearest to the pumping station (Figure 5.2).

In CPB, elevation differences and tail-head relations were primary sources of irrigation problems. The zone halfway between sectors B and C (marked with oblique lines in Figure 5.3) received smaller discharges as it is supplied by the most downstream secondary of the main canal. The minimum tertiary canal IIA, 0.41 (Table 5.6), was found here. The zone in sector A marked with oblique lines in Figure 5.3 is slightly higher (7.5 m asl) than the rest of the scheme (5−7 m asl). This implied the occurrence of irrigation problems, indicated by a tertiary canal IIA of 0.67.

In M’Pourie, sector 5 (Figure 5.4) is higher elevated than the other sectors; however, special care in the water delivery to this sector prevented the appearance of irrigation problems (Figure 5.4).

Underperforming irrigation infrastructure, for which main causes were degradation and poor design, exacerbated constraints mentioned earlier. The pumping station was an element of great precariousness in M’Pourie and CPB, where, due to frequent burn-downs, water supply was threatened. Main canal systems were degraded to different levels in the three schemes. Worst conditions were encountered in CPB and PPGII. In the latter, none of the automatic float-operated gates, the sole hydraulic structures to control water flows in the main canal, functioned as by design: two out of five did no longer control water levels; the remaining three had lost calibration. Tampering with water control structures was widely observed in the three schemes and was at the same time cause and consequence of infrastructure deterioration. Poor canal weeding at tertiary unit level had major consequences on water distribution to fields: in M’Pourie and CPB about one third of the sampled tertiary canals had drastically reduced capacity due to dense vegetation; this proportion rose to 50 % in PPGII.

Physical deterioration of the irrigation systems increased complexity of operation activities. Nevertheless, in two of the three schemes (CPB and M’Pourie) specific operational measures and the experience of irrigation staff could partially compensate for sub-optimal physical water control and limit crop damages. In PPGII, insufficient operation personnel at main system level and the non- application of organised water distribution rules at tertiary level impeded to balance out poor technical water control.

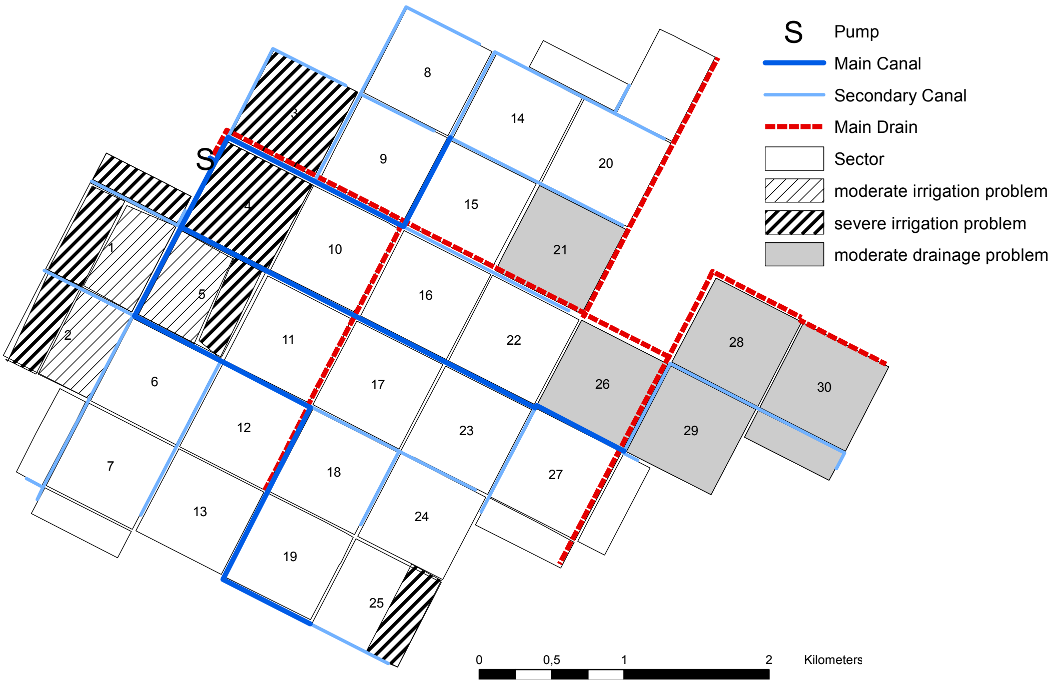

Figure 5.2. Ground survey-based mapping of irrigation and drainage problem zones in PPGII irrigation scheme. Zones marked with oblique lines indicate moderate (thin lines) or severe (thick lines) irrigation problems. Grey shading indicates zones with moderate drainage problems and black shading, zones with severe drainage problems.

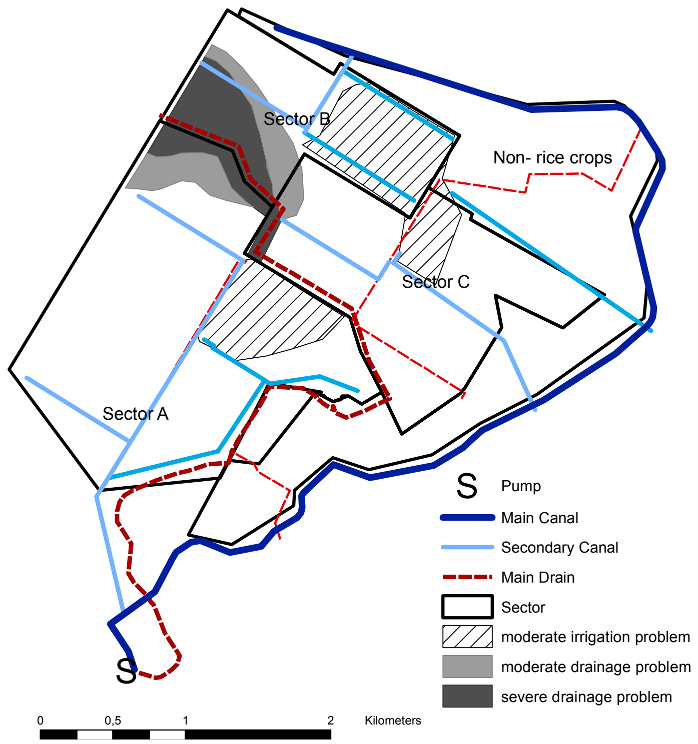

Figure 5.3. Ground survey-based mapping of irrigation and drainage problem zones in CPB irrigation scheme. Zones marked with oblique lines indicate moderate (thin lines) or severe (thick lines) irrigation problems. Grey shading indicates zones with moderate drainage problems and black shading, zones with severe drainage problems.

Figure 5.4. Ground survey-based mapping of irrigation and drainage problem zones in M'Pourie irrigation scheme. Zones marked with oblique lines indicate moderate (thin lines) or severe (thick lines) irrigation problems. Grey shading indicates zones with moderate drainage problems and black shading, zones with severe drainage problems.

Table 5.6. Indicator of irrigation adequacy (IIA), indicator of drainage adequacy (IDA), irrigation intensity (II) and harvest intensity (HI), and yield (Y) of sampled tertiary canals in the three studied large-scale irrigation schemes.

Scheme	*Statistic*	*IIA*	*IDA*	*II*	*HI*	*Y (t ha^{-1})*
PPGII 2010	Mean	0.8	0.87	0.82	0.96	3.75
	Min	0.4	0.65	0	0.69	0.93
	Max	0.99	1	1	1	6.97
	CV	0.17	0.12	0.31	0.07	0.35
High zones	Mean	0.69	0.88	0.41	0.98	3.27
	Min	0.4	0.65	0	0.96	0.93
	Max	0.99	1	0.9	1	5.65
	CV	0.28	0.15	0.93	0.02	0.42
Intermediate zones	Mean	0.84	0.83	0.88	0.95	4.07
	Min	0.81	0.82	0.47	0.69	1.9
	Max	0.87	0.83	1	1	6.11
	CV	0.03	0.01	0.14	0.08	0.3
Low zones	Mean	0.87	0.89	0.97	0.95	3.88
	Min	0.78	0.72	0.86	0.84	1.38
	Max	0.99	1	1	1	6.97
	CV	0.09	0.14	0.05	0.07	0.32
CPB 2010	Mean	0.77	0.85	0.92	0.97	3.66
	Min	0.41	0.5	0.34	0.67	0.96
	Max	1	1	1	1	8.59
	CV	0.27	0.23	0.2	0.1	0.39
M'Pourie 2009	Mean	−	−	0.49	0.84	1.88
	Min	−	−	0	0.56	0.07
	Max	−	−	0.88	1	4.1
	CV	−	−	0.67	0.19	0.55
M'Pourie 2010	Mean	0.91	0.62	0.68	0.89	3.24
	Min	0.67	0.33	0.38	0.8	0.4
	Max	1	1	1	0.97	7.04
	CV	0.15	0.35	0.34	0.06	0.41

Drainage problems

Drainage problems, which heavy rains fallen during the wet season 2010 (441 mm in Rosso, 282 mm in Boghe, and 528 mm in Kaedi) have surely contributed to, posed at least as much challenges as irrigation. Drainage problems were first detected through field observations and, later, cross-checked with Landsat images. Dark-grey regions in Figure 5.6 and Figure 5.7, that indicate high infrared reflectance and, thus, the presence of an inundated area, corresponded to areas in CPB and M'Pourie that, according to ground surveys, had severe drainage problems (Figure 5.3 and Figure 5.4). The infrared reflectance map of PPGII (Figure 5.5) indicated that drainage problems were only moderate in this scheme, in accordance with ground observations in the sampled tertiary canals and the overall survey (Figure 5.2). The satellite images were a useful means to gain information about areas that were not included in the sample of tertiary canals and allowed thus to draw more general conclusions. For instance, in M'Pourie high infrared reflectance was detected in sectors 1 and 2 (Figure 5.7), which confirmed drainage problems reported by the private service provider.

Drainage problems had two main causes: the presence of natural depressions where water accumulated, and faulty drainage infrastructure. These two factors, which were manifest in the three irrigation schemes, were strongly related as drainage infrastructure worsened topography-induced drainage problems.

However, it was still possible to attribute drainage problems to the first or second cause according to their respective incidence. Topography was the foremost cause of drainage problems in CPB and PPGII. In the latter scheme, moderate drainage problems affected downstream zones of the scheme (eastern side, Figure 5.5) that form part of a natural depression, where both irrigation and rain water converged. Minimum tertiary canal IDA (0.48) was observed there (Table 5.6). In CPB, severe drainage problems were detected in a lower zone next to the main collector that gets recurrently inundated (grey to black pixels at the north-west side of the scheme, Figure 5.6). The minimum tertiary canal IDA observed in CPB (0.5) was precisely in that zone (Table 5.6).

In M'Pourie, more than of topographical nature, water-logging derived from a defective drainage network. The west end's main collector was no longer connected to the pumping station thus preventing drainage water to be pumped back in the river. This caused clogging of main and secondary drains and water spilling back onto fields located nearby. Moreover, the proliferation of highly invasive aquatic plants, concretely *Typha australis*, in the main drain significantly reduced its capacity and rendered its maintenance difficult and labour intensive.

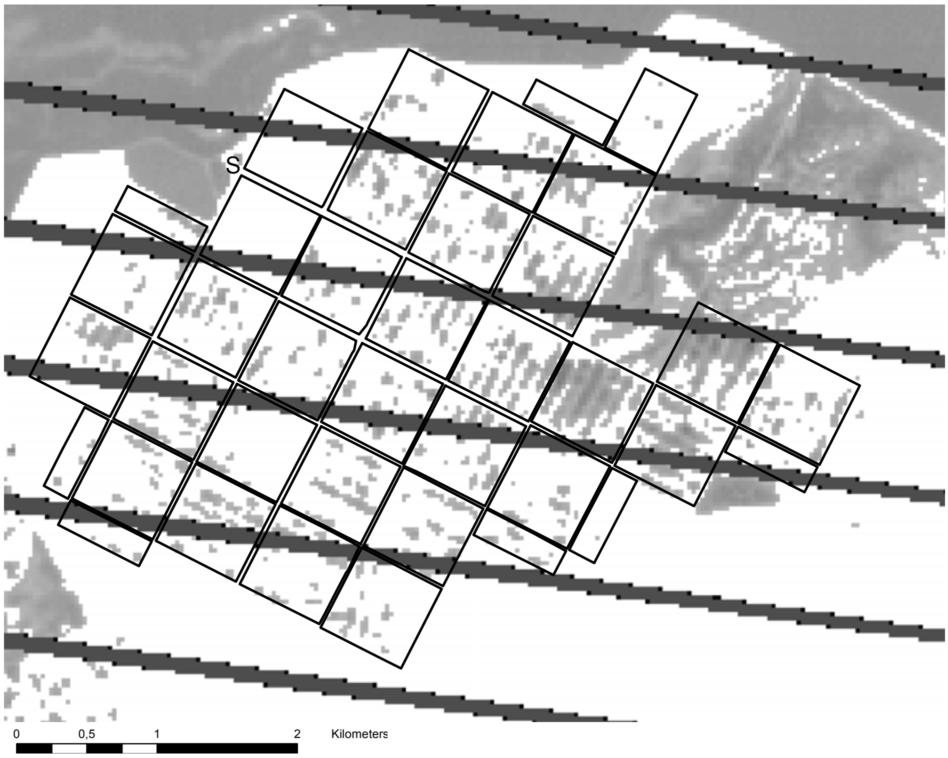

Figure 5.5. Map of drainage problems based on infrared reflectance measured from Landsat satellite over PPGII irrigation scheme. (The thick parallel lines across the image have no meaning; they are just a defect of the Landsat 7 satellite sensor.)

Figure 5.6. Map of drainage problems based on infrared reflectance measured from Landsat satellite over CPB irrigation scheme.

Figure 5.7. Map of drainage problems based on infrared reflectance measured from Landsat satellite over M'Pourie irrigation scheme.

5.4.2. Irrigation and harvest intensity

During 2009 wet season, PPGII and CPB did not cultivate (II = 0) and II for M'Pourie was much lower than in 2010 (0.49 vs. 0.68, Table 5.6). Physical (irrigation and drainage problems reported in Section 5.4.1), institutional and organisational factors were at the origin of this situation. The rigid financing procedures of 2009 −state credit was frozen due to highly indebted cooperatives– was the foremost determinant of not cultivating CPB in 2009. In M'Pourie, only farmers who could afford to self-finance the production were able to cultivate that year; which explained the greater II coefficient of variation in 2009 compared to 2010 (Table 5.6). In PPGII, cultivation was hindered also by rehabilitation works on part of the irrigation and drainage network that had been severely damaged by an inundation in 2007. Being credit reintroduced and thanks to state subsidies for rice cultivation, participation in production in 2010 was expectedly high in the three irrigation schemes.

In 2010, II in the three schemes was largely determined by drainage and irrigation problems causing the abandonment of part of the irrigable area. Areas prone to drainage problems in M'Pourie were inundated during intense rain events in July and August

(164 mm), which explains the lower value of II in M'Pourie (0.68), compared to PPGII (0.82) and CPB (0.92) (Table 5.6). Within each irrigation scheme, II varied between the different zones. M'Pourie showed the greatest variability (Table 5.6). Lowest II was registered in sectors 5, 6, 10, and 11 (with a minimum value of 0.38 in sector 10, Table 5.6) due to the high presence of moderate and severe drainage problems (grey and dark-grey zones in Figure 5.4, respectively). In CPB, too, an area of 40 ha could not be cultivated, being it located within a zone of severe drainage problems (dark-grey zone in Figure 5.3).

In PPGII, the non-cultivation of part of the scheme was primarily associated with severe irrigation problems in the upstream area (dark-grey oblique lines in Figure 5.2). Here, low II at cooperative level ranged from 0.5 to 0. Of the planted area, part could not be harvested. Harvest intensity (HI), defined as harvested surface over irrigated surface, was 0.89 in M'Pourie, 0.97 in CPB, and 0.96 in PPGII (Table 5.6). Harvest intensity varied across the irrigation schemes and this variability was somewhat, too, related to irrigation and drainage conditions. HI values were calculated at sector level in M'Pourie and at cooperative level in CPB and PPGII. In M'Pourie, minimum HI was 0.80 (Table 5.6), in sector 4, that, according to Figure 5.4 and Figure 5.7, was affected by severe drainage problems. In 2009, due to exceptional rainfall during the month of August (252 mm), the link between HI and drainage problems was even more evident: HI was 0.68 in sector 4 and was lowest (0.56) in sector 6 (Table 5.6).

In CPB, the lowest HI at cooperative level (0.67) was mostly imputable to the shortage of water on plots located in a zone previously identified as problematic in terms of irrigation (light-grey oblique lines in sector A, Figure 5.3).

5.4.3. Land productivity

In the three irrigation schemes, average grain (paddy rice) productivity was comparable to average yield of rice schemes in Mauritania reported by Aquastat (FAO, 2005) but lower than attainable yields for the same area and conditions, estimated between 8 and 9 t ha^{-1} (Haefele et al., 2001). Average yields were 3.15 t ha^{-1} in M'Pourie, 3.63 t ha^{-1} in CPB and 3.72 t ha^{-1} in PPGII, although variability was considerable (Table 5.6). Plot grain yield ranged from 0.4 to 8.8 t ha^{-1} in M'Pourie, 0.96−8.6 t ha^{-1} in CPB, and 0.93−7 t ha^{-1} in PPGII. These intervals were consistent with those obtained in other studies in the same region (Haefele et al., 2001; Poussin et al., 2003; see Chapter 4).

Tail-head relations along tertiary canals have been widely reported to be responsible of accruing yield variability. Yet, the present study showed that whilst in two of the three schemes mean yield at the head of the tertiary canals was generally higher than at the tail, there was also great variability between tertiary canals and, in several cases, tail mean was higher than head mean. Overall, the differences were not statistically significant (Table 5.7), which indicated that other sources of variability intervened.

Non-uniform water distribution and drainage proved to be major causes of yield variability between tertiary canals and between secondary canals. The comparison of yield recorded in zones with drainage or irrigation problems (Figures 5.2−5.4) with those in zones without problems revealed that the differences were statistically significant in the three irrigation schemes (Table 5.7). As a matter of fact, low productivity was recorded in tail end areas (CPB) – this was also detected by Poussin et al. (2006) – in lower or higher elevated zones (CPB, PPGII, and M'Pourie) or, again, in areas where the drainage network was saturated. The same analysis applied to 2009 data for M'Pourie confirmed results of 2010: mean yield of cooperatives located in zones without irrigation or drainage problems was statistically greater than mean yield in zones presenting drainage problems (2.34 vs. 1.10 t ha^{-1}, Table 5.7).

Table 5.7. Mean yield (t ha^{-1}) in the three studied large-scale irrigation schemes (PPGII, CPB, M'Pourie). Comparison of mean yield between tertiary canals' head and tail and between zones affected and unaffected by drainage or irrigation problems. Figures in each pair followed by a different letter were statistically different at P = 0.05 level of significance.

Scheme	*PPGII*	*CPB*	*M'Pourie 2009*	*M'Pourie 2010*
Mean	3.72	3.63	1.82	3.15
Head	3.90 a	3.65 a		3.49 a
Tail	3.37 a	3.75 a		3.10 a
Zones with moderate problem	3.35 a	3.14 a	1.10 a	2.90 a
Zones with severe problem	4.10 b	4.40 b	2.34 b	3.90 b

The cooperative was also taken as a unit of analysis in order to see if there were significant differences between their yield means that could explain variability. However, there was no evidence for asserting that the organisational factor had an influence on yields. In M'Pourie, those cooperatives whose low mean yield in 2010 was statistically different from the means of the rest of cooperatives had 70−100 % of their plots located in zones with drainage problems. In PPGII, the cooperative whose mean yield was statistically lower than the rest had plots in the higher elevated area with irrigation problems. In CPB, having the cooperatives under study plots in the three sectors with different physical and technical characteristics, allowed to better segregate the factor "organisation" from "physical conditions". The result was that yield differences between cooperatives were not statistically significant. This last example provided additional and meaningful support to the argument that yield variability matched the heterogeneous conditions of irrigation and drainage at system level.

The high availability of satellite images for M'Pourie in 2009 (7 images, Table 5.5) and the timing of the 3 images available in 2010 allowed to confidently interpolate daily NDVI values along the rice growing season for simulating yields using the crop yield model. Unfortunately, we did not find any correlation between measured and simulated yield (Figure 5.8). Measured yield showed much larger variation than simulated yield (coefficients of variation, respectively, 0.51 and 0.15, in 2009, and 0.30 and 0.14, in 2010), i.e., the NDVI-based model did not capture most of the yield variation observed in M'Pourie. A possible explanation was that rice crops in the Senegal valley are often infested with weeds (Poussin et al., 2003), which are not distinguishable from rice when calculating NDVI. In our field surveys, weeds infestation was a common observation. Moreover, average yield was overestimated in 2009 and underestimated in 2010. Since fertilizer supply was short in 2009, likely insufficient nitrogen was one of the factors explaining the difference between both years. Apparently, this effect was not captured by the crop yield model. Based on these results, we desisted from detecting yield variability patterns based on satellite images. Also, we concluded that yield variation patterns obtained using this methodology in similar agricultural systems without ground truthing, such as the study conducted by Zwart and Leclert (2010) should be interpreted with caution.

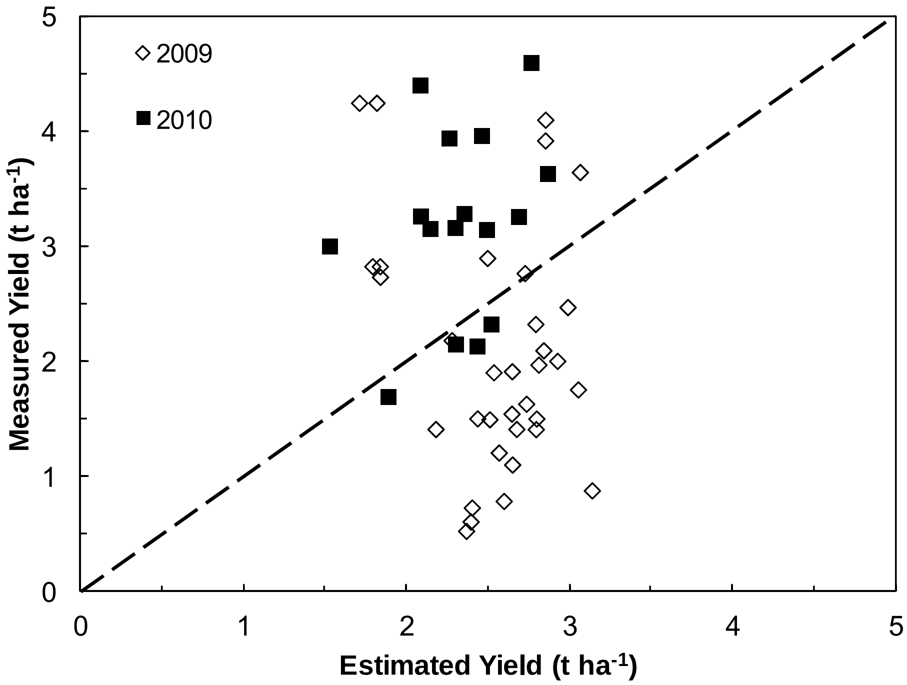

Figure 5.8. Measured vs. simulated average yield of tertiary canals in M'Pourie, years 2009 and 2010.

5.5. Discussion

Mean values of performance indicators showed that performance gap was little between the three irrigation schemes (Table 5.6). However, within each scheme, variability with respect to II and yield was noteworthy. A main point in the present discussion is that spatial patterns of land productivity and irrigation intensity detected in the studied irrigation schemes were to a great extent driven by heterogeneous conditions of irrigation and drainage. These resulted from physical (topography, location in the system) and technical (state of drainage and irrigation infrastructure and water management) constraints. Many authors have contributed to shed lights over the link between internal irrigation processes and external indicators such as water and land productivity. It was argued by these authors that a productive system is one that produces in a uniform way over its surface and that uniform and high productivity are linked to the uniformity (Clemmens, 2006; Clemmens and Molden, 2007), equity (Steiner and Walter, 1992; Jahromi and Feyen, 2001), reliability and adequacy (Jahromi and Feyen, 2001) of water distribution. Thus, by analysing the variance in water distribution along different canal branches it is possible to estimate productivity levels in the various branches. Our analysis deepened in this relation between internal irrigation processes and land productivity although taking as starting point yield variability instead of water distribution uniformity. Latif (2007) already reported spatial distribution of wheat productivity in a canal irrigation system in Pakistan. The focus of that study was on the effects of the location of farms and showed how productivity significantly reduced with the distance from the head of main, secondary, and tertiary canals as an aftermath of unreliable irrigation at the tail ends. The present study expands to other factors causing spatial productivity and introduces drainage as a crucial, though often underrated aspect in producing low agricultural production and low irrigation intensities in the study area. Whilst water shortages have a direct impact on crop productivity, inadequate drainage has rather indirect effects on rice productivity. Excess water hinders accessibility to fields (Smedema et al., 2000) and, thus, farming practices like weed control, harvest, and land preparation.

Table 5.8 presents the coefficient of variation of yield measured at various system levels: between plots located along a same tertiary canal, between tertiary canals along a same secondary, and between secondary canals. Overall, variability increased at lower system levels and it was highest between plots of a same tertiary canal. This finding suggested that variability among plots primarily depended upon single farmer's discretion, his/her capacity to manage the plot, and his/her strategies to overcome limitations by the cooperative. In fact, correct and timely fertilizer application and weed control have often been reported to be main causes of the gap between actual and attainable yields in the Senegal Valley (Haefele et al., 2001; Poussin et al., 2003).

Table 5.8. Coefficient of variation of yield determined at various system levels: between plots located along a same tertiary canal (CV_{plot}), between tertiary canals along a same secondary ($CV_{tertiary}$), and between secondary canals ($CV_{secondary}$).

Scheme	CV_{plot}	$CV_{tertiary}$	$CV_{secondary}$
M'Pourie	0.25	0.19	0.26
CPB	0.36	0.25	0.18
PPGII	0.34	0.20	0.12

However, the relatively high coefficient of variation of yield between secondary canals and between tertiary canals (Table 5.8) highlighted the importance of the drainage and water delivery services in explaining the patterns of variation found in the studied schemes. Global adequacy at tertiary canal level, taken as the minimum between IIA and IDA, explained 35 % of yield variability between tertiary canals (Figure 5.9).

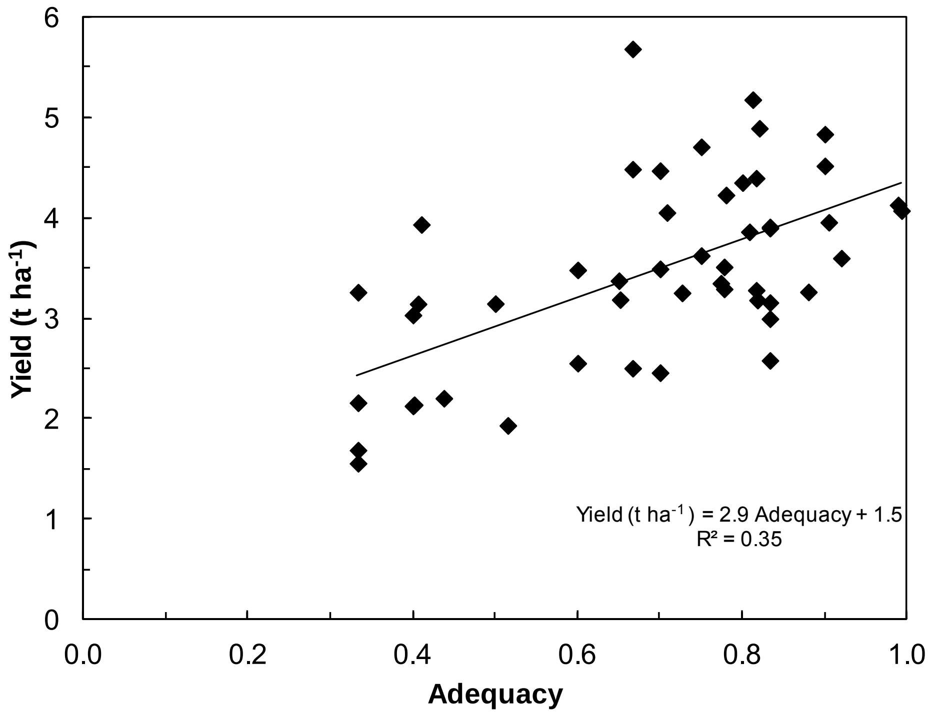

Figure 5.9. Average rice yield of tertiary canals vs. global adequacy (minimum value between the indicators of irrigation and drainage adequacy).

Disturbances in the water flow are created at the interfaces between the concatenated system levels and transmitted downstream (Clemmens, 2006). The effect of all water distribution disturbances cumulates at plot level. Already at the water source, pumping was unreliable in the studied irrigation schemes as pumping stations were old and the capacity to operate and maintain them, low. Repetitious interference of farmers in the regulation of gates and manipulations of structures challenged irrigation management and indicated a lack of transparency and understanding of irrigation procedures. The deterioration of structures, negligence in canal maintenance, and lack of sufficiently skilled personnel for system operation likely contributed to unequal water distribution. The float-operated gates in M'Pourie and PPGII, which in the latter scheme should have permitted a completely automated water distribution, were no longer functional and were operated manually by farmers and irrigation staff. Maintenance rules, if any, were rarely applied and task division between the state irrigation agency and farmers was fuzzy. Moreover, farmers seemed to be unwilling to engage in maintenance amid uncertain positive returns. If it is true, as Clemmens (2006) argues, that variances in the main canal trickle down to lower hierarchical canal levels in an amplified fashion at each lower canal, then, Mauritanian large-scale irrigation schemes should be more fragile than small-scale schemes as the former have more hierarchical levels of infrastructure, management and operation.

Whilst low awareness of the benefits of drainage and, consequently, lack of drainage development have characterised past interventions in the developing world (Smedema and Ochs, 1998), the present paper advocates for improved drainage conditions for raising agricultural production and irrigation intensities. Indeed, overall, the present study showed that drainage problems and consequent water-logging were more important factors in determining II than were irrigation problems. The loss of land through uncontrolled water-logging and raising salinity threatens food security and poverty alleviation (Smedema et al., 2000). Studies conducted in the Office du Niger by Vandersypen et al. (2006, 2007) already lifted the issue of drainage in rice cultivation and its implications at the time of harvesting the crop. The studied Mauritanian irrigation schemes shared some of the causes of drainage problems with the Office du Niger – lack of maintenance of drains and interconnectedness of the drainage network. However, contrarily to the Office du Niger, the clogging of drains was not a consequence of over-irrigation (Vandersypen et al., 2007) but rather the combination of adverse topographical conditions, defective drainage facilities, and insufficient maintenance.

Strikingly enough, the factor "cooperative" (whether a cooperative scored higher yields than another) had no influence on productivity (comparison of means yielded not statistically significant differences at the probability level P = 0.05), which somehow does not match what the collective organisation in place would suggest (Poussin et al., 2006). Moreover, in M'Pourie, neither the type of land user (private farmer vs. cooperative) seemed to have any effect on productivity as differences were not statistically significant (3.1 t ha^{-1} vs. 3.2 t ha^{-1}, respectively; $P > 0.05$).

We have thus far discerned about irrigation and drainage problems causing low and variable productivity and II. Our study revealed that organisational and socio-economic factors were main causes for changes over time of II. For instance, the increase of II from 2009 to 2010 in M'Pourie was a combined effect of subsidies and facilitated credit, and the participation of private farmers who cultivated plots rented from cooperatives of M'Pourie. Moreover, the shortage of fertilizer supply at national scale in 2009 explained the increase in average yield in 2010 (1.82 vs. 3.15 t ha^{-1}). In 2009, the cause of no cultivation in CPB was that cooperatives lost eligibility for credit because of debts, and they did not have the financial means to buy production assets. In PPGII, the incapacity to timely organise effective rehabilitation works after the inundation of 2007 lead to delayed and summarily executed rehabilitation works during 2009, which impeded the cultivation of rice during the wet season.

5.6. Conclusions

The performance evaluation of three representative large-scale irrigation schemes in Mauritania highlighted great intra-scheme variability with respect to as crucial indicators as yield and irrigation intensity. Whilst variability in yield proved greatest among single plots, which is explicable by single farmer's livelihood strategies and capacity to manage the plot, variability was also notable between tertiary canals and between secondary canals.

The analysis of water distribution patterns at scheme level indicated that these played a central role in determining the spatial distribution of yield and irrigation intensity in the three studied schemes. Physical (topography), technical (defective design and deterioration of irrigation and drainage infrastructure), and organisational (lack of specialised irrigation personnel, insufficient maintenance) factors underlie observed irrigation and drainage problems.

Often little considered, drainage turned out to have even greater influence than irrigation on both yield and irrigation intensity. Field surveys and the reflectance in the infrared band using Landsat 5 and 7 satellite images showed causal relation between inundation-prone areas and low yield and/or low irrigation intensity.

Whilst irrigation and drainage determined spatial variability, socio-economic and organisational factors, concretely, access to campaign loans and rehabilitation procedures, influenced temporal variability of yield and irrigation intensity.

Variability in production jeopardises the sustainability of large-scale schemes and the achievement of national objectives such as food security and food self-sufficiency. The authors argue that the awareness of intra-scheme variability and the understanding of the driving forces at play have implications for the definition of national irrigation policies and interventions.

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Chapter 6

Comparing alternative irrigation models in Mauritania. How to break the degradation spiral for food security?

6. Comparing alternative irrigation models in Mauritania. How to break the degradation spiral for food security?

6.1. What role do the different irrigation models play for food security?

Having discussed rice schemes more in depth in Chapters 3−5, I will now reintroduce alternative irrigation models presented in Chapter 2, delving into their respective contributions to food security and livelihoods, altogether with rice schemes, and proposing concrete and fundamental steps for their improvement.

6.1.1. The role of small individual irrigation (SII)

In the Senegal valley, smallholder irrigation has been the focus of development policies and practice since the 1970s, for its indubitable potential in addressing food insecurity and poverty (Keller and Roberts, 2004; World Bank, 2008; Jayne et al., 2010; Burney and Naylor, 2012; Poulton et al., 2010; Hazell et al., 2010). SII is spatially confined to some dozen meters river outwards, thus, the area and number of people reached by this type of irrigation are small. Contrarily to collective rice schemes (LPS and SCMS), which are mainly oriented towards auto-consumption, SII can produce marketable surpluses. Moreover, being this type of farming generally vegetable-oriented, it represents an important source of nutrients for enriching local diets.

Factors that favour the introduction of this irrigation model are: easy to manage irrigation technology, relatively low cost of investment, and positive returns on this investment. The cost of small pump-served irrigation systems provided through the VISA project varied between 760 and 890 € ha^{-1}, while average net margins (including amortisation of the water distribution system) of about 800 € ha^{-1} $year^{-1}$ were typical (Diallo, 2011). However, although unitary costs of investment are much lower than those of LPS and SCMS, these costs, contrarily to what happens in collective schemes, are taken up individually by farmers, which might be prohibitive for the poorest unless co-financing by a donor institution intervenes. A related problem is the poor access to credit for individual micro-farmers (Jayne et al., 2010; Burney and Naylor, 2012), who represent a high risk for financial institutions and commercial banks (Sonou and Abric, 2010). Moreover, inadequate post-harvest services and lack of appropriate infrastructure are hampering access to markets and thus the development of sustainable smallholder farming (Barbier et al., 2011; Poulton et al., 2010).

Yet, if only the farm is considered, today, there is a full range of household-level irrigation technology, which has been tailored to fit the need of the most vulnerable and poor (Keller and Roberts, 2004). Provided the scale and level of irrigation technology is well chosen and the system well designed in order to simultaneously address water access, water distribution, and a productive use of water (Burney and Naylor, 2012), this irrigation model is promising in terms of manageability, increase in productivity, and potential in reducing poverty.

6.1.2. The role of women garden (WG)

Whilst in other Sahelian countries irrigation and the irrigated crop remain a male's prerogative, in Mauritania women may actively engage in weeding, irrigating, and harvesting rice. Diemer and Huibers (1991) reported that Black African women, wolof, haalpular, and soninké, commonly worked in rice fields and might have even be obliged to work on their husband's plot against labourer's wage. Our study largely confirmed earlier testimonies (Van der Laan, 1984; Diemer and Huibers, 1991; Crousse et al., 1991) that lack of male labour due to migration to neighbouring countries and Europe has widely shifted roles in rice farming with increasing responsibility allocated to women. Women may also manage rice irrigation schemes: in this research, among the 22 SCMS studied, 2 were run by cooperatives of women.

However, the main role of women in the provision of food to villages in the Senegal valley revolves around the production of vegetables. 19 of the 22 villages whose SMCS were studied had also a WG managed by a cooperative of women. Crops grown vary slightly according to the region. In Trarza, for instance, fruit trees may be grown additionally to vegetables, whereas in Brakna, peanuts and maize complete the cropping pattern. These crops complement staple crops (produced either under irrigation, flood recession, or rainfed) in satisfying nutritional needs.

4 of the 19 surveyed WG borrowed one pump and other irrigation equipment from the village rice scheme, while in the other 12 the pump was owned by the cooperative of women. However, despite good relationships with men-led rice schemes, most women

cooperatives complained that they lacked a water distribution system for efficiently distributing water in their gardens as it was not included in the relief packages delivered to them by local NGOs. Furthermore, lack of financial assets was frequently reported as a big handicap for reliable water provision and production.

6.1.3. The role of private irrigation schemes (PIS) and agribusiness (AB)

PIS are concentrated in the region of Trarza. After an initial period of expansion, cultivated surfaces under PIS began to shrink and in 2000 less than half the surface cultivated in 1990 remained so (Sally and Abernethy, 2001). In 2008, there were 11,401 ha of PIS in Trarza, 185 ha in Brakna, and 8 ha in Gorgol (DPCSE, unpublished results). It appeared that PIS did not escape from several of the problems faced by collective schemes: poor design and construction (reflecting both limited financial and technical capacity), low investments undertaken, land degradation due to insufficient drainage, increased costs of production, and poor and fluctuating availability of inputs (Sally and Abernethy, 2001).

The great surface cultivated in PIS and the vocation towards rice production makes this irrigation model an important supplier of staple food to local and national markets. Furthermore, PIS employs local labourers and often makes machinery (tractor, soil labour equipment and harvester) available for rent to other small farmers in the area. Yet, the potential and debilities of private irrigation remain largely undocumented.

Agribusiness has only recently made its appearance in Mauritania. At the time when the research team left the country in 2011, this type of enterprise was still limited and did not yet compete with existing local farming. However, the great availability of land and water resources, coupled with the pace at which these endeavours are expanding in other countries of the Sahel, suggests that AB will also have repercussions for rural and agricultural developments in Mauritania.

The role of agro-industry for food security and local sustainable agricultural development is controversial (Barbier et al., 2011; Brondeau, 2011; Deininger and Byerlee, 2012) mainly because of the uncertainty attached to private investors and their "dynamics of establishment" (Sylla, 2006). Supporting views argue that agribusiness could play a critical role for food security through the supply of national markets as it supposes large surfaces, high use of inputs, and high productivity. Yet, it is also widely recognised that these businesses are primarily oriented towards international markets or externalisation of production (e.g. Libya) (Brondeau, 2011).

6.1.4. The role of large public schemes (LPS) and small community-managed schemes (SCMS)

Whilst traditional flood recession and rainfed farming alone do not suffice for meeting households' energetic needs, its combination with irrigated rice has increased the likelihood to meeting households' cereal consumptions in the villages along the valley (Comas et al., 2012). Additionally, collective irrigation schemes have greater social impact than private irrigation because they give access to irrigated plots to a large number of peasants irrespective of their social condition or their land tenancy titles. Because production costs and assets are shared within the village community, this model makes irrigation potentially accessible to the most vulnerable.

Despite their undeniable contribution to food security, most LPS and SMCS are unsustainable at actual productivity thresholds and management practices. Low productivity and profitability offer two possible interpretations. A first argues that negative margins do not signify that irrigated rice is not profitable *per se*. Rather, "unprofitable yields" are sustained by the availability of liquidity generated by migration remittances (Lavigne Delville, 1991) and other off-farm activities. In fact, land users often prefer to minimise production costs rather than increasing yields and revenues (Adamczewski et al., 2011). A second interpretation alleges that the degradation and abandonment of irrigation might be looked at as consequences of unprofitable yields and negative returns to labour and inputs (Comas et al., 2012). According to in-depth analyses presented in Chapters 3−5, the degradation of LPS and SMCS can be described as a negative feedback process whereby the poor functioning of one aspect generates a secondary effect that in turn intensifies the primary problem (see Chapter 4). In Figure 6.1 the 20 studied irrigation schemes are plotted along the degradation spiral according to the benchmarking analysis performed in Chapter 3 that evaluated their land productivity, relative irrigation supplies, and energy costs. There are three comments to make here. First, there is great variability in their performance and the presence of relatively well functioning schemes is encouraging. Second, SCMS (small circles) do not outperform LPS (big circles). Third, rehabilitations, which should restore initial conditions, often do not introduce significant improvements to the performance of schemes, either because of poor implementation of works or because they imply new design concepts that derive from wrong assumptions. The impact of rehabilitation on performance is reflected by the respective location of rehabilitated (grey circles) and non-rehabilitated (black circles) schemes along the spiral of degradation: overall, rehabilitated schemes performed better, yet the difference was quite irrelevant when compared to costs of rehabilitation (see Chapter 4). Moreover, there were non-rehabilitated schemes performing very similarly to rehabilitated ones and, in turn, one rehabilitated scheme was near the threshold of abandonment (Figure 6.1).

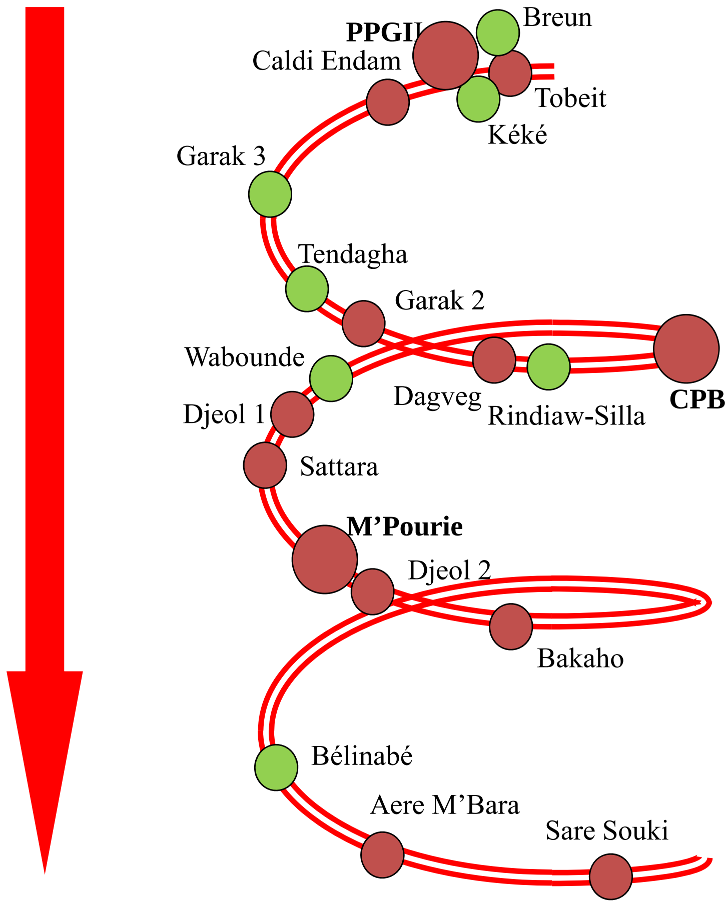

Figure 6.1. Studied irrigation schemes plotted along the degradation spiral according to benchmarking analysis (see Chapter 3).

Consequently, rice schemes are continuously dependent on external aid in form of both subsidies and periodical physical rehabilitation. Rehabilitation policies pursued so far by the government and international developers are partly responsible for this dependency by continuously and unconditionally intervening with new rehabilitations.

This has disheartened grass-root commitment to invest in irrigation, and the process, known as the “rehabilitation followed by deterioration trap” (FAO, 1999), has triggered assistance mentality among water users in LPS and SCMS. LPS present the additional inconvenient that if performance and productivity do not improve, they are not economically viable and, consequently, not transferrable to water users.

6.2. Where from here?

I have thus far outlined the role of different existing irrigation models for food security in Mauritania, their problems and weaknesses. This section seeks for propositions and solutions for their improvement with a special focus on LPS and SMCS. Performance improvement of rice schemes will need a fundamental shift in its approach and in guiding principles applied so far for irrigation schemes’ rehabilitation and irrigation management transfer. Although incentives for increasing irrigation performance shall be understood within broader boundaries of the agricultural, socio-economic, and institutional systems (Small and Svendsen, 1990), there are still concrete measures that can be undertaken within the boundaries of the irrigation system.

Through time, the focus in irrigation development has oscillated from pure hydraulic engineering to social sciences in an attempt to move away from technical solutions and instead to pay more attention to improving irrigation management. Yet, in the last 20 years, there has been growing awareness about irrigation as an interdisciplinary subject (Burton 1989; Horst, 1998; Plusquellec, 2002; Laycock, 2007) where hardware and software dimensions interrelate and are equally important. This new school of thought argues that improvement in management alone yields marginal successes if it is not accompanied by the introduction of physical water control at crucial system interfaces (Clemmens, 2006).

Here, several measures for performance improvement are suggested that address both software and hardware dimensions. Many of these notions are not new and have been thoroughly researched and applied in the field of irrigation. What is proposed here new is rather a change in approach and in the order of actions, conceptualised in Figure 6.2.

6.2.1. *Improving software and hardware components*

Improving water delivery service is viewed by many as a crucial means to increase system performance and productivity (Styles and Marino, 2002; Burt and Styles, 2004; Clemmens, 2006; Molden et al., 2007). Complex technology and opaque operational procedures, combined with lack of skilled personnel, are often at the root of poor service quality and performance (Horst, 1998). Yet, primitive technology does not contribute with better results either: it is unacceptable to deprive developing rural settings from new technology that could save time, labour, and resources while making the rural context more attractive to younger generations and agriculture more sustainable. Thus, key questions are: What is the appropriate technology? Where to start in order to bridge the gap between technology and management? How to foster local investment in maintaining irrigation schemes at sustainable levels?

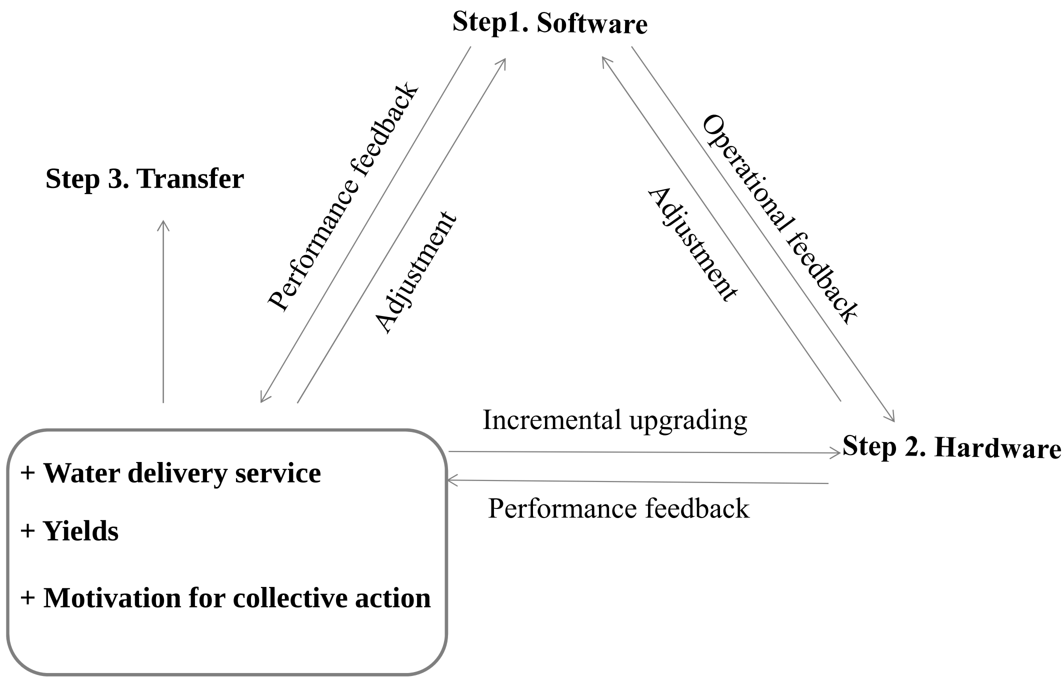

Figure 6.2. Framework for improving collective rice schemes: drivers, linkages, and outcomes.

First software

The point made here is that software improvement should be best sought before physical improvement is undertaken or, at least, at the same time (Figure 6.2). First, because there are cases where performance could be raised in much more effective ways through improved operation and maintenance rather than through rehabilitation (Mateos et al., 2010). Second, because awareness and capacity raising widens possibilities for farmers and irrigation staff to significantly participate in the planning and design process by suggesting solutions that best reflect local needs and habits. If the order is inverted (physical improvement first), costly investment in hardware will most probably not yield forecasted effects on productivity and irrigation performance.

In Mauritania there is an established legal framework that regulates farmer cooperatives adapted to existing village social arrangements. The social organisation of the village is reproduced in irrigation management at scheme level in SCMS, and at tertiary unit level in LPS. Furthermore, water users within each scheme are relatively homogeneous (smallholders), except in large schemes in Trarza where there is also a minor component of medium-size commercial land users. Therefore, on a general basis, the conditions for collective action (Bandaragoda, 1999; Kolavalli and Brewer, 1999; Meinzen-Dick et al., 2002) in rice schemes are given.

While there is social and institutional ground for collective action, technical capacity of irrigation staff, farmers, and their governing bodies shall be significantly improved. Mauritania lacks irrigation planners and engineers. This is a constraint which national policies should tackle immediately by giving Mauritanian students access to graduate and postgraduate programs on water resources and irrigation planning and management at universities abroad. Meanwhile, the government of Mauritania should develop a strong national education system for training irrigation specialists.

On the other side, management, operation and maintenance in SCMS are at the reach of local expertise, which is reflected by the existence of several performing schemes (see Chapter 4; see Chapter 3). Of course, any measure for enhancing literacy, accounting, empowerment, transparency, and institutional relationships in the water users cooperative boards will contribute to the effectiveness of collective irrigation. Training should have a large participative basis and include all interested stakeholders that engage in productive activities or cover management functions relative to the irrigation schemes. Performing schemes should be taken as reference for improving less efficient schemes. Field visits and *in-situ* participatory learning processes are a great opportunity to build on local knowledge (Krupnik et al., 2012). While SONADER used to play an important role in developing and advising the irrigation sector, the decentralisation process has substantially reduced its capacity. However, collaboration with local staff during the field research showed that there are technicians capable of managing, operating and maintaining irrigation schemes, but they will need to be provided with training and advice.

By contrast, as there is no local expertise in managing large irrigation systems, training of irrigation managers and operators in LPS will require assistance from abroad. LPS irrigation staff should be made familiar with complex pumping stations and hydraulic structures, flow responses to gate operation, and canal control principles and practices.

Besides training, irrigation managers in both SCMS and LPS should be provided with tailored operation and maintenance protocols and simple tools for decision support. Awareness should be raised on the importance and benefits of preventative and routine maintenance (FAO, 1982; Skogerboe and Merkley, 1996); then, maintenance plans and execution control should be implemented. Pumping energy use, which makes averagely 30 % of production costs but is highly variable in small schemes (see Chapter 4), should be subjected to technical audits conducted by specialised professionals aiming at informing on actual practices and ways to improve them. Technically sound water delivery scheduling is key to curtail energy costs by minimising operational water losses while improving adequacy of water supply, another well reported cause of variable and low yields (Poussin et al., 2006; see Chapter 4; see Chapter 5). During low water requirement periods, improved delivery schedules could be achieved by concentrating water diversions spatially and temporally, thus avoiding small discharges scattered over the whole system that imply greater water losses. During peak demand periods, continuous instead of rotational supply, or extending the hours of irrigation per day would enhance both distribution efficiency and adequacy. Constraints for night irrigation should be considered and, where possible, resolved.

Altogether, training of irrigation operators and farmers in charge of irrigation management is expected to increase their self-confidence and prompt respect and trust among water users. Although improvement in irrigation management and maintenance alone does not guarantee an effective control over the water delivery process, for which complementary physical upgrading is required, there will be undeniable positive returns (Okada et al., 2008). Most importantly, starting with less costly software ameliorations helps avoiding overestimations of physical interventions (Burt, 2011).

Then hardware

A wealth of research has been dedicated to the multiple dimensions of irrigation and the relations between technology and organisational and operational requirements (Horst, 1998; Mollinga, 2003). Yet in the practice, irrigation technology and design are still too often disregarded as causes of poor management and performance of irrigation schemes (Plusquellec, 2002).

In Mauritania, problems related to technology and infrastructure are of three kinds: degradation, misconception, and mismatch between technology and management. In the former case, an upgrade would imply rehabilitation work. For instance, improving drainage, which was major cause for low and variable yields in large schemes (see Chapter 5), could be achieved through maintenance and reshaping of drains; irregular topographical elevation and consequent drainage/irrigation problems could be partially solved by laser levelling. In order to avoid rapid degradation after physical upgrading, we suggest that investment on the infrastructure should be gradual and incremental. Successive interventions should be conditioned to positive returns to O&M training and capacity building discussed before (Figure 6.2).

The second problem, design misconception, requires reengineering the whole system (Renault, 2001). A frequent misconception is related to the hierarchical organization of the water distribution system. As Clemmens (2006) explained, disturbances in the flow at higher system levels trickle down to lower system levels in an amplified manner, causing unreliability and inequity in water distribution. This was frequent observation in the studied large schemes in Mauritania. As for small schemes, Mateos et al. (2010) reported the case of a rehabilitation where two initially hydraulically independent sectors had been unified under a centralised water source, which increased unreliability. The solution is to break down the irrigation system into independently supplied sectors. This can be achieved either right at the water source (e.g., separate pumping stations) or, in LPS, at main system level by assuring on demand water supply to secondary inlets. Constant water levels in the main canal of LPS are obtained either through manual gate operation or by means of automatic hydraulic gates. Mismatch between technology and management, the third type of problem related to technology and infrastructure, may then arise.

The study of LPS in Mauritania (see Chapter 5) exemplifies the often cited divide between design assumptions and operational reality (Burns, 1993; Plusquellec, 2002).

As an example, successive interventions in irrigation infrastructure aiming at incrementing canal control by means of automatic float-operated gates have in fact increased complexity without providing the required level of O&M skills. As a matter of fact, none of these float-operated gates ever worked as by design, so staff operates them manually, which is inefficient and cumbersome. The point I would like to make is that physical improvements should opt for an appropriate level of technology that counts with farmers' systems of understanding and capacity of local institutions and irrigation staff to manage the system and finance O&M costs. Canal control should be an iterative exercise fuelled by constant feedback from operational performance (Clemmens, 2006) and management progresses as a consequence of training (Figure 6.2). If skilled staff is available and canal capacity sufficient, then there is no specific need for automating the entire canal system, or there is no need to do it at once.

Participation of stakeholders shall be sought from the initial stages of irrigation planning and design as a transversal element. If supported by experienced external facilitation, participation can provide a more comprehensive understanding of complex socio-technical processes (Reed, 2008). If not result of a transparent exchange between planners and stakeholders, physical interventions aiming at bringing about improvements are likely to fail.

6.2.2. Irrigation management transfer (IMT) and financing mechanisms of LPS

According to the study of three representative LPS, the different degree in which responsibilities and authority in irrigation management had been handed over to farmers' organisations depended on their social cohesion, managerial and technical capacity, and engagement in collective action. Among the three schemes, one showed positive signs in this sense; its cooperatives requested full control over O&M budget because they thought they could be more cost efficient than the state agency. In a second LPS, political/ethnical contrasts between village cooperatives held back complete transfer of responsibilities. Nevertheless, on a general basis there is evidence that the union of cooperatives managerial model works fairly well in Mauritania. By contrast, the public-private managerial model that operated in the third LPS in our study did not yield positive results: since 2005, the private contractor providing the water service has changed three times, each time leaving irrigation and drainage infrastructures in state of great disrepair.

Rather than unviability of IMT to cooperatives, mixed results in Mauritania reflect the hastiness of state agencies in retreating from irrigation management before actually creating the conditions for transfer. There is no single IMT model, so each country or region has to proceed at its own pace according to local socio-economic, technical, and institutional circumstances (FAO, 2007). To my understanding, it is worthwhile to continue supporting cooperatives in the IMT process. For this, transfer shall be preceded and accompanied by both capacity building of managing entities and technical upgrading in the ways described in section 6.2.1. Once positive returns on these improvements become visible in terms of overall performance, productivity, and finances, a complete transfer of LPS can be envisaged (Figure 6.2).

There is wide consensus in that expenses for irrigation O&M have to be largely financed through water fees paid by farmers (Vermillion, 1997). However, current maintenance practices in Mauritania are highly insufficient and water fees do no nearly reflect the level of maintenance needed for long-term life of irrigation infrastructure. Fee recovery rates are low and highly variable (<30−70 % in studied cooperatives during the wet season 2008−2009). Making farmers pay for all O&M costs may appear quite unrealistic today. Yet, if complete transfer is pursued after, and not before, substantial performance and productivity improvement, as proposed here, farmers shall be more able and willing to increasingly contribute to O&M costs. A complete transfer has to be accompanied by measures and policies that impulse local commitment by stimulating organisations of farmers to keep up with agreed performance standards. The state could continue contributing with some shares to the costs of irrigation, but the financing strategy should change (Vermillion, 1997). Farmers still largely think that it is the state's responsibility to guarantee for physical reparations and maintenance of main canal systems; however, in the future, funding for O&M should be subordinated to farmers' involvement in irrigation management and to positive feedback in terms of performance. It is thus impellent that the state clarifies once for all its irrigation funding policy.

6.2.3. Diversification in rice schemes

Crop diversification is one of the main goals of the IDPIAM. However, participatory research in Mauritania has identified numerous constraints to diversification of crops in rice schemes (Boivin et al., 1993; García-Ponce et al., 2012). These schemes were designed specifically for rice with the objective of maintaining a constant water depth of 10−20 cm on the plots. Soils are clayed and laboured to reduce infiltration. This creates a spatial limitation to the introduction of crops other than rice, which badly tolerate saturated soil conditions (García-Ponce et al., 2012). Moreover, irrigation delivery schedules are rigid and rice-driven. With irrigation turns of 10−15 days, which are commonly used by rice growers, vegetables inevitably incur in water stress conditions (Boivin et al., 1993). Even the starting of the irrigation season is determined by the needs of rice. Additional problems emerge when there are delays in the main rice cropping season, that impede planning a further non-rice crop during the dry period.

Therefore, diversification will only be a feasible option if rice schemes undergo major technical and organisational changes. First, technical design of rice schemes has to be adjusted in such way to allow physical separation that prevents water infiltration from paddy to non-rice fields (e.g., non-rice crops should be cultivated at the periphery of rice schemes or on separate sectors). Second, irrigation delivery scheduling in non-rice plots should be independent from paddy. This implies that water should be supplied to these plots by separate pumps. Temporal separation between rice and non-rice crops, i.e., rice-non-rice double cropping, requires optimal organisation of the crop calendar in order to make best use of seasonal climatic conditions (Verheye, 1995). This will require control of specific external factors such as availability of machinery for soil preparation, credit, and inputs, for which national agricultural policies should provide for (García-Ponce et al., 2012).

6.2.4. Other irrigation models

Women horticultural gardens have already established themselves as valid technological solutions for improving incomes and general livelihoods of the rural poor. The VISA project has proved that small individual irrigation is technically and economically viable as well. Yet, technological and agronomic advances have not been equally matched with the development of a supportive environment of institutions and services for the self-replication of these production systems. It is thus evident that the potential of smallholder irrigation to generate income and alleviate poverty becomes manifest only when irrigation and production technologies are integrated with the accessibility to a full range of complementary goods and services (Keller and Roberts, 2004; Poulton et al., 2010). Specifically, these are financing mechanisms, the development of rural markets and infrastructure to access them, price stability, input markets, and post-harvest facilities to ensure adequate storage of highly perishable products (Weinberger and Lumpkin, 2007).

Women gardens are similar to rice schemes with regard to their cooperative organisation and may thus need other additional type of support than small individual schemes such as training in collective activities, administration, and irrigation management. Moreover, recognising the “feminisation of agriculture” (Molden et al., 2007) in Sub-Saharan Africa is a necessary step towards the design of tailored measures for women farming.

Private local irrigation has proven very dynamic in Mauritania and needs to be further characterised in terms of management, technology adopted, assets and access to services, so as to be able to develop a framework for their prosperous and sustainable development. Legal and institutional arrangements are needed that both regulate and monitor the environmental and socio-economic sustainability of agribusiness, to safeguard interests of local farming and livelihoods systems (Deininger and Byerlee, 2012).

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Chapter 7

Conclusions and Recommendations

7. Conclusions and recommendations

7.1. Conclusions

Performance assessment and benchmarking analysis of small community-managed and large public rice schemes drives to the following conclusions:

1. Degraded infrastructures, insufficient maintenance practices, inadequate service delivery were main causes for low and variable land productivity and performance, yet
2. Extreme variability in yields and performance between irrigation schemes and the existence of several well organised schemes where plot yields greater than 7 t ha^{-1} are frequent are positive signs for improvement and indicate that the small community-managed schemes model fits the socio-economic conditions of the Senegal River valley.
3. Great intra-scheme variability in large schemes was directly related to heterogeneous water distribution patters caused by technical, physical, and organisational factors.
4. Inadequate drainage was a main cause for intra-scheme yield variability in large schemes.
5. Comparable productivity and efficiency in resources use of small and large schemes indicate that both irrigation models sustain staple food production and food security and shall thus be equally supported.
6. Performance and productivity must increase− many schemes are still below the threshold of viability −especially in large schemes otherwise they will not be transferable to users.

7.2. Recommendations

The analysis of existing alternative irrigation models in Mauritania and their potential contribution for food security led to the following recommendations on how to improve them:

1. Improvement in system operation and management should be best sought before physical improvements, or at least at the same time, to avoid overestimations of physical interventions needed.
2. Extensive training and capacity building is needed at all levels (farmers, technicians, engineers), it should have a large participative and grass-root basis while also be supported by both experienced professionals and tailored tools for supporting decisions.
3. The quality of design and construction shall improve substantially in order to bridge the gap between technology level and management capacity. For this, both good engineering and participatory processes are required.
4. A new design concept is needed that considers breaking down the irrigation schemes into independent sectors and/or system levels through improved physical and organisational control. This shall increase accountancy, reliability, and adequacy. Whether it is to be achieved through technology and/or human-organisational control, shall depend on site specific conditions.
5. Drainage, especially in large schemes must be improved through mechanical work and up-to-date technology (e.g., laser levelling)
6. Physical upgrading should be incremental and further external investments should be subordinated to positive feedback from training in terms of improved water delivery service.
7. Irrigation management transfer should be viewed as a process, not as an end. As such, it should start with increasing performance of large schemes through training and physical upgrading. Only once productivity and economic viability are raised, the scheme can be transferred completely to farmers.
8. The cooperative model as a managing institution for irrigation schemes has proved to work in Mauritania, conversely to public-private models of governance. Thus, farmers' cooperatives shall be supported by all means so as to ensure their technical and managerial capacity to take over management of large schemes.
9. Diversification in rice schemes requires changes in both design concepts and irrigation management in order to physically and organisationally separate rice from non-rice sectors.

10. Other irrigation models based on horticulture and higher value crops merit equal attention, although they cannot substitute staple food production. Efforts to improve these irrigation models shall be directed to the creation of services and institutions upstream and downstream of the farm. For this, financing sources, the development of secondary industries and farmer-driven organisations for purchasing inputs, innovative technology production, know-how development and advocacy, are fundamental.
11. Local, private irrigation, for its potential contribution to food security, deserves greater and specific study of its actual reach in terms of surfaces and productivity, weaknesses and strengths. Recent developments and threats rising in other countries of the Sahel related to agribusiness projects and land grabbing call for close control of these endeavours. For this, legal and institutional arrangements are needed to monitor and secure socio-economic and environmental sustainability of these endeavours while safeguarding rights to access resources and production to different categories of traditional inhabitants.
12. Boundary conditions (institutions, markets, services) are fundamental in determining the possibility for irrigated agriculture to develop and thrive. For this, coherent and integrated rural and agricultural policies targeting small and medium commercial farming have to be developed in order to encourage higher productivity. To be motivated enough to increase yields, farmers should see in irrigation an appealing opportunity to invest further shares of their household's budget. Alternatively, they will persevere with low input production models pursued so far or even abandon irrigation.
13. The quality of policy formulation and implementation largely depends on the quality and soundness of statistical data available, for which the establishment of a dynamic inventory based on both extensive field surveys and measurements, and geographic information systems, is needed.